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USE OF THE PITOT TUBE AND MANOMETER OR RECORDER IN MAKING WATER-FLOW AND PRESSURE STUDIES.

BY HUBERT B. SMITH.*

[*Read September 19, 1929.*]

The important function of any distribution system is to furnish at all times an adequate supply of water at adequate pressure. Although the cost of distribution mains represents the major investment of a water-works system, the mains are many times not observed with the same care as the filter plant, pumps and other appurtenances. Their condition, however, is very often the real answer to adequate supply and pressure.

While it may not be considered of vital importance for the water-works engineer to be an expert on flow and pressure tests, he will find it to his advantage to be able to run a water-flow and pressure investigation himself, particularly if he finds it necessary to solve some of the problems that will be outlined. It is not intended to advocate that the engineer make a comprehensive water-waste survey. In the average-sized community his duties are too varied, and the day is usually too short. Also there are available the services of several companies who specialize in such work. The training and experience of these companies usually leads to a more rapid and economical solution of the problem.

The object of this paper, therefore, is to bring to the attention of the water-works engineer the latent information contained in the data and results obtained either by an investigation of his own or in a survey made by others.

A system whose original design was considered ideal may prove inadequate after a decade, due to shifting centers of population, changes in industries, and other influences. Data such as maximum rate of consumption and fire demand, obtained by flow and pressure investigations for the entire city, as well as any section of it, will in many cases permit the engineer to anticipate, and keep abreast of the demand upon the system. He will thus be enabled to provide uniformly excellent service at all points in the system.

In many communities, a policy has been established whereby outside agencies are called in, every year or two, to make a complete check or water-waste survey of the system. The data and information obtained should be

*Simplex Valve and Meter Company, Philadelphia, Pa.

as valuable and necessary to the water-works engineer as the usual accepted inventories of stock taken by the manufacturer. Included in the records should be the data obtained by the engineer himself during the intervals between the water-waste surveys, thus providing a complete knowledge of the performance of the distribution system at all times.

In order to carry on an investigation the engineer should have certain pieces of equipment. This equipment should be considered just as important as some of the equipment in the filter plant which is considered indispensable. The writer believes that as the engineer becomes acquainted with the uses of such equipment he will regard them as of equal importance.

There should be provided a suitable meter, pressure gages, and possibly leak-locating devices. The best type of meter for this purpose, in the writer's opinion is a Pitot tube either with an indicating manometer or with a sensitive instrument to record the rate of flow on a chart. This recording instrument may be equipped with a pressure element to provide simultaneous readings of both velocity and pressure.

The Pitot tube and manometer or recorder is particularly adapted for the purpose, because it is accurate over a wide range of flow and flexible in its application. The same instrument can be used in any size of main, and for a number of different purposes. The equipment furthermore is portable and rugged, and can be quickly and easily put into service. It provides either an indication, or in the case of the recorder, a graphic record from which an intelligent study of the flow can be made. When the recorder is employed, finally, there is no need for stationing an observer continuously at the meter, inasmuch as a continuous record is given by the instrument.

The uses of the Pitot tube and manometer or recorder are many. It can be used to meter the discharge from a pump to determine the slip or pump efficiency. It can be employed to check large commercial meters without interruption of service since there is no need for removing the meter. The equipment is applicable in ascertaining the flow in a main for which a permanent meter installation is proposed. This makes it possible to specify intelligently the range of flow required for the permanent meter. The flow and loss of head in a pipe line can be simultaneously measured to determine the necessity of and data for designing pipe lines. Any part of a distribution system may be surveyed for reliable data upon which to base extensions and reinforcing of the system. Such data afford substantial and valuable evidence in rate cases. For determining leakage and waste and locating their sources the instruments are especially well adapted.

Having discussed the adaptability and uses of the Pitot tube as applied to water-works maintenance, it might be well to describe briefly its principles and the method of operation.

The Pitot tube is a primary device and, like an orifice, or Venturi tube, is used to create a differential pressure. As shown in Fig. 1, it consists of two concentric tubes (or a tube within a tube), the lower ends of which terminate in orifices. The Pitot tube is introduced into the water main and

aligned so that the orifice in the outer tube faces upstream. This opening then receives the impact of the flowing water and is, therefore, called the impact orifice, while the orifices of the inner tube are placed at right angles to the direction of flow, thus receiving the reference pressure which is always less than that obtaining at the impact orifice.

If the pressure effect of the Pitot tube is transmitted to two vertical open pipes, or piezometers, water will rise in the one connected to the impact orifice to a height equal to the total head due to both velocity and pressure at the position of the impact orifice in the pipe. The water in the other pipe which is connected to the reference orifices will rise to a height equal to the pressure head minus the suction effect of the reference orifices. The difference H between the two heads or pressures is a measure of the velocity of the water flowing past the orifices of the Pitot tube. This differential head varies in a definite and known relation to the rate of flow, so that

$$V = c\sqrt{2g\,H}$$

Where V equals velocity in feet per second, c is the coefficient of the Pitot tube, g is the gravity constant, and H, as before, is the differential pressure in feet of water, sometimes called the Pitot head. This is the fundamental principle of the Pitot tube.

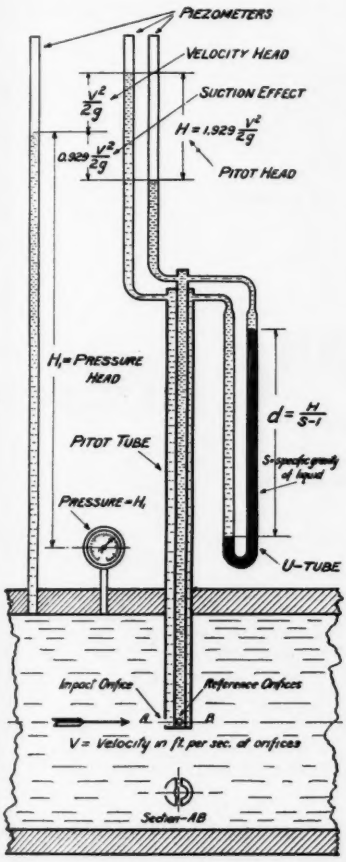

FIG. 1.— HYDRAULIC ELEMENTS OF THE PITOT TUBE.

In practice the impact and reference pressures from the Pitot tube are connected either to a U-tube manometer or to a recording instrument. With further reference to Fig. 1, the differential pressure H plus the difference in level of the water in the U-tube is balanced by the head h, of the liquid in the U-tube. This is the simplest kind of device for indicating the rate of flow which may be expressed as:

$$V = C\sqrt{2gh\,(S\text{-}1)}$$

Here S is the specific gravity of the balancing liquid in the U-tube, h is the

deflection in inches, and C is the Pitot-tube coefficient reduced by converting deflection in feet to inches.

The Pitot tube shown in Fig. 2, is designed to be attached and inserted through a 1-in. corporation cock. It is provided with a standard form of stuffing box making a water-tight joint about the tube. The Pitot tube recorder shown in Fig. 2 is operated by the differential pressure acting on a bell-shaped float. The travel of this float is always proportional to the velocity in the main, and its movement is transmitted by a cable over a

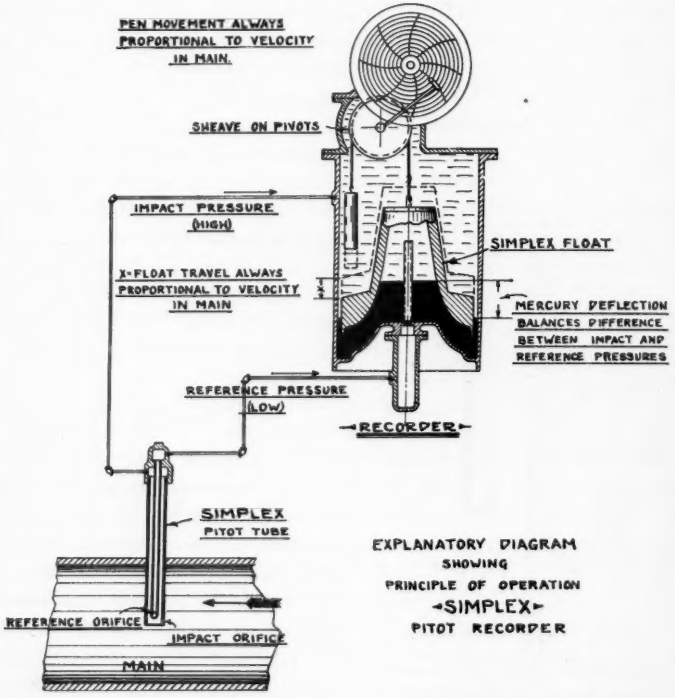
PEN MOVEMENT ALWAYS PROPORTIONAL TO VELOCITY IN MAIN.
SHEAVE ON PIVOTS
IMPACT PRESSURE (HIGH)
SIMPLEX FLOAT
X-FLOAT TRAVEL ALWAYS PROPORTIONAL TO VELOCITY IN MAIN
MERCURY DEFLECTION BALANCES DIFFERENCE BETWEEN IMPACT AND REFERENCE PRESSURES
REFERENCE PRESSURE (LOW)
RECORDER
SIMPLEX PITOT TUBE
REFERENCE ORIFICE
IMPACT ORIFICE
MAIN
EXPLANATORY DIAGRAM SHOWING PRINCIPLE OF OPERATION SIMPLEX PITOT RECORDER

FIG. 2.— PITOT TUBE, MANOMETER AND RECORDER INSTALLED FOR USE.

sheave directly to the recording pen, which provides a continuous record of the velocity in the pipe line. The shape of the float is such that the chart can be uniformly graduated.

This type of recorder is capable of measuring velocities from 0.5 up to 11 ft. per sec. Its general design is such that it permits easy handling in the field, and can be moved from place to place.

There is furnished with each recorder a manometer-testing outfit, whereby the instrument may be checked at any time by water columns of fixed values corresponding to various pipe velocities. By reading the cali-

bration scale these values can be checked from 1 up to 6 ft. per sec. Sometimes these recorders are provided with a pressure element so that simultaneous values of velocity and pressure can be obtained.

Let us now take a typical city, and outline briefly the problems that presented themselves in a certain case to the engineer. Figure 3 shows the distribution system for a community of about 15 000 population. The supply is derived from mountain streams and is collected in an impounding reservoir. From the reservoir it flows by gravity through a 12-in. main

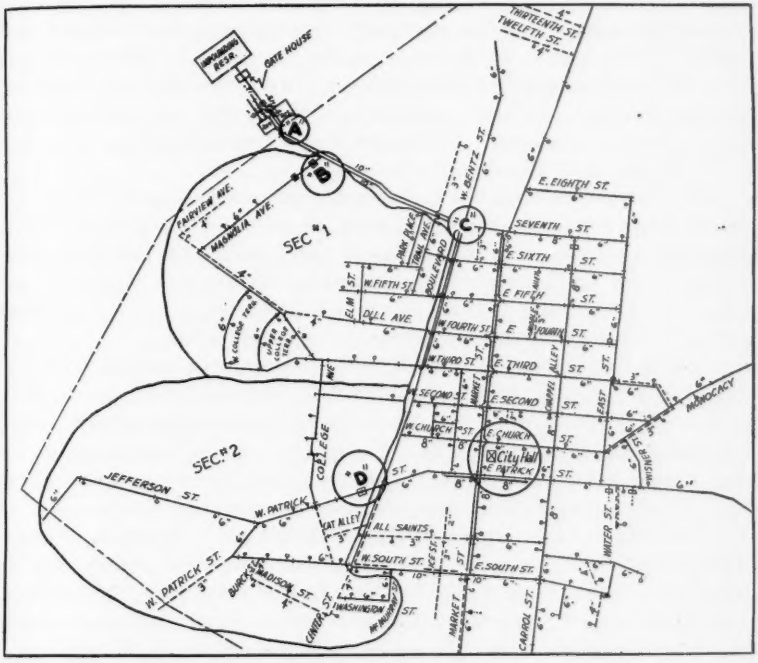

FIG. 3.— DISTRIBUTION SYSTEM EXEMPLIFYING PROBLEMS IN WATER-FLOW AND PRESSURE STUDIES.

about 5 miles long. The elevation at the intake is about 1 200 ft. above point *A* where a Venturi meter is located This meter indicates, records and totalizes the flow into the city and affords a daily history of the amount of consumption, the period and duration of peak loads and minimum consumption. There is installed near the Venturi meter a pressure-reducing valve, manually operated. This valve is set so that a pressure gage installed at the City Hall, registers about 40 lb. per sq. in. during the day.

Chlorine is introduced into the supply at the gatehouse at the reservoir. The line between the reservoir and the Venturi meter is walked over about

monthly, and leakage is detected by water coming to the surface, except where the main crosses two marshes and a small stream.

Serious water famines have been averted by quick action at times when the Venturi meter showed inadequate flow into the city, indicating that most of the supply was being dissipated upstream from the meter. This condition was due to the fact that while the run-off into the impounding reservoir was at all times ample to provide for maximum demand within the city, it would not take care of excessive leakage. It was found advisable to divide the five miles of 12-in. pipe into stations and place 1-in. corporation cocks at such points. By introducing a Pitot tube through the corporation cock at the intake, the quantity of water passing this point was definitely determined. By the use of another Pitot tube, introduced at any of the intermediate stations, any discrepancy in the amount of flow between the reservoir and station in question was immediately detected and the leakage area thus isolated. By the use of sounding instruments the point of leakage was determined and corrected.

The fact that chlorine was introduced at the gatehouse and that dosage was based on actual rate of consumption, as shown by the Venturi meter, made it desirable to check the amount of water passing the intake in order to sterilize the entire supply as prescribed by the Board of Health. This may be considered an additional advantage for placing a corporation cock at the intake for determining the flow at any time desired.

The second problem that had to be considered was between points *A* and *C*, here two 10-in. mains, about 2 500 ft. long divided the entire flow to the city. The engineer found it necessary to determine whether each was carrying its share of the load. The method adopted was to make two taps on each line at points *A* and *C*. It was then necessary to isolate these mains by shutting off any cross-connections between these points.

Introducing Pitot tubes into the mains through corporation cocks at *A* and *C* for either main the quantity flowing past these points was determined. By knowing in addition the pressure coincident with velocity determinations, all of which was obtained with pressure gages, the friction characteristics of the respective mains was also determined. It was found that due to excessive tuberculation, their carrying capacities had been greatly impaired. It was also discovered that valves which were supposedly open had been left partly or entirely closed. This in reality covered the actual work done. As we proceed to analyse the system, however, it becomes apparent that it is possible to make pressure and flow investigations almost anywhere in the distribution system without causing service interruptions or structural changes. To do this we may proceed to divide the entire system into districts (see sections 1 and 2), selection of which is purely arbitrary.

The gaging point is established on some main, of a small size, say 6 in., the governing factor being that the size of the main be sufficient to supply the entire section in question for a period of from 24 to 48 hours (see point

B). Periodic measurements are taken, say once a year, and if the city is metered, the flow is checked against the total amount accounted for on the individual meters within the section, or based on the estimated consumption per capita, if not measured. Such gaging points, through street connections, are made permanent and readily available in valve box enclosures.

By covering the entire city in this manner, these records can be observed and compared from year to year, thus serving as a history of the pipe efficiencies and carrying capacities. Such a scheme is becoming common practice with many municipalities; for example, Ottawa, Canada, maintains control by putting crews to work at regular intervals. Working is usually begun at the outskirts of the city. The department has a previous record of the total water flow in each district, together with the population. The men then determine if there is an increase or decrease in consumption, by measuring the flow at various gaging points. If an abnormal increase is found, the area is subdivided and brought down block by block until the trouble is located. The entire city is covered this way once a year.

There has been no attempt to go into great detail and cover every step required in the making of flow or pressure studies. Many different kinds of problems of this nature present themselves to the water-works engineer, but it is believed that if periodical water-flow and pressure investigations are made, and these are supported with a continual check by the engineer, complete control of the distribution system can be maintained.

In closing the writer wishes to point out several advantages that will accrue to practically every water-works plant that makes a practice of conducting periodical water-waste surveys.

Additional capital expenditures for pumping-station enlargements, for increased filter-plant capacity, and for larger mains are often postponed for several years because leaks in the distribution system are located and repaired, thus conserving the water and enabling the plant to utilize all the water supply for useful purposes rather than permitting a considerable percentage of it to be wasted. The financial advantage to any water plant under such circumstances is very substantial. Even though the plant has the advantage of a large water supply the survey benefits the plant in that all waste detected and corrected reduces pumping and filtration costs. Many water companies have been penalized by Public Service Commissions in rate cases where it was found that the water unaccounted for was excessive. In such cases Commissions invariably reduce the allowable operating expenses to a sum equal to that which would prevail in a plant that is economically operated. Here again a water survey would eliminate the possibility of the plant being charged with extravagance in its operating methods, and in the event that a rate case was in prospect, the plant engineer who knows and can prove that his water unaccounted for is at a minimum will be in an advantageous position when presenting his case to the Commission. Last but not least is the satisfaction which comes to every one as a result of doing a thing well, and knowing all about his plant.

A regular check-up of the distribution system will put every water-works engineer that follows this course in a position to know all about his plant at any time that he is called upon for information. This is not only helpful to the plant, in a financial way, but in addition, it places the water-works engineer in a most desirable position before the owners of his plant, who cannot fail to recognize the ability and foresight displayed by the engineer.

THE SUBMARINE PIPE-LINE BETWEEN PORTLAND, ME., AND GREAT DIAMOND ISLAND.

BY HARRY U. FULLER.*

[*Read September 25, 1930.*]

One of the most interesting pieces of construction recently completed in Maine is a submarine pipe-line laid in 1929 in Casco Bay.

In this bay Peaks, Diamond and other islands lie about two miles offshore from Portland, while Mackworth's Island is about one half mile offshore. Fort McKinley is on Great Diamond Island, and the other islands have a large summer population.

In 1918 the federal government laid an 8-in. submarine pipe-line from the mainland to Mackworth's Island, crossed the island with ordinary pipe and then continued with submarine pipe to Great Diamond Island. From here, common pipe was laid to the Fort. The contour of the bottom crossed the mouth of a river with a depth of 30 ft. and for about a mile varied between 15 and 25 ft. in depth. The material encountered on the line was blue clay overlaid with from one to two feet of silt. On three shores, ledge was found; the fourth shore was a sand beach.

The section of submarine pipe between the mainland and Mackworth's Island was buried about 6 ft., but the other section about 7 000 ft. in length was laid on the bottom without being trenched. The work was completed at a cost of $200 000, and the water turned into the line. Shortly after completion it was found that the line was leaking badly, and a diver was employed to find and stop the leaks. For about two years, divers worked intermittently. About a dozen special castings were placed around joints that had pulled apart, and a large number of clamps were placed on joints to keep them from opening up. It was said that divers caulked practically every joint in their attempt to make the line tight. After $50 000 had been spent on repairs, all attempt to use the line was abandoned.

Negotiations with the War Department were concluded in 1929, and the Portland Water District undertook the burden of supplying Fort McKinley with water and became the owner of the abandoned line.

Investigations before Rebuilding.

Information was desired concerning the character of the material that would be found on the line. Divers who had worked on repairs reported that the softest material was about 2 000 ft. east from Mackworth's Island. A dredge with a 1-cu. yd. bucket was sent to this point to dredge an experimental trench. About 75 ft. of trench were excavated, and the material

*Chief Engineer, Portland Water District, Portland, Me.

placed about 40 ft. to one side. Soundings showed that the trench was 5 ft. deep, 10 ft. wide at the top and 5 ft. wide at the bottom. A week later, soundings at the trench showed no material change. Soundings were made over the entire length of the line with a 40-ft. piece of 1-in. pipe. There was no difficulty in churning this sounding rod 6 ft. into the underlying clay.

The particular part of the line that had proved to be least stable was the crossing of the river mouth. Here it was reported that the scouring action of the river water had undermined the pipe and that quantities of rock riprap failed to hold the material in place. It was, therefore, decided to carry the pipe at this place on a pile and cap foundation. Piles were driven to determine their carrying capacity.

The divers who had worked on repairing the line reported that the unburied part could be easily found, as a large part of it had not settled out of sight in the silt. It was decided to attempt salvaging as much of the old pipe as could easily and economically be obtained. It was found feasible over much of the distance to pick up the pipe near one shore with an anchor and after getting a rope under the pipe, to hoist the pipe aboard in sections of two or three lengths. The pipe parted readily at the joints, where there were no clamps, without injury to the pipe, but there were some sections of the line where the lead had to be melted from the joints after the line was raised above water. A diver was used a few times to recover the end of the pipe where it had parted under water. Over 800 ft. of this pipe were eventually machined and used in the reconstructed line. All told, about 5 300 ft. of pipe were salvaged with very few damaged lengths. The machined surfaces of the bells and spigots were found to be slightly corroded, but it was thought that a small amount of machine work might put them in shape to be used again. This was tried and found to be successful. Milling machinery was arranged to take a small cut from both the bell and ball ends of four sections. A test was then made by running the joints with lead, plugging both ends, and introducing water at 80 lb. per sq. in. pressure at one end. The sections were then moved about, deflecting the joints to their full limit. After several movements of a joint, a small leakage would appear, but a caulking tool quickly corrected the difficulty. As an interesting experiment, the lead was removed from the joints, and they were then filled with a jointing compound. Under water pressure, the results seemed to be fully as good as those obtained with lead joints.

Scope of Work in 1929.

In 1929, the work consisted of laying a 12-in. main 1 700 ft. long between the mainland and Mackworth's Island and an 8-in. main 6 800 ft. long between Mackworth's Island and Great Diamond Island. The pipe was purchased by the Water District from the U. S. Pipe & Foundry Company and delivered to the contractor on a convenient wharf.

Bids. Bids were received on April 29, 1929. They were as follows:

Pipe.		Bay State Dredging and Contracting Co.		Merritt Chapman and Scott.		Bennett Contracting Corp.	
Length. Ft.	Diameter. In.	Unit Price.	Total Bid.	Unit Price.	Total Bid.	Unit Price.	Total Bid.
1 700	12	$10.28	$17 476	$11.00	$18 700	$13.50	$22 950
6 800	8	9.20	62 560	8.60	58 480	7.65	52 020
Total			$80 036		$77 180		$74 970

The contract was let to the lowest bidder. He had previously laid a 16-in. submarine line in Portland Harbor and had done other submarine work, thereby demonstrating his ability.

Equipment. The contractor provided a lighter 28 x 80 ft. having an 80-ft. boom for handling the pipe and pipe chute; a lighter 20 x 54 ft. rigged with a derrick for excavating and back filling, and a pile driver 24 x 54 ft. The lighter used for excavating was provided with outrider pontoons to give greater stability.

On a similar job this contractor had previously laid the pipe by means of curved chute suspended between two lighters. On this job, he made a change in the method of holding the chute. He built a tower of timbers properly trussed which rested on the bottom of the bay and extended above high water. Attached to this tower was the curved chute used for laying the pipe. The legs of the tower were fastened to skids which formed the feet of the structure. In general appearance, this apparatus suggested a giraffe with his four legs standing well apart. (See accompanying figure.) This tower spanned the trench which had been previously dredged. The lower end of the chute extended downward into the trench, and served to smooth off any irregularities left by the bucket in dredging.

The pipe-laying chute was about 90 ft. long and of such curvature that the pipe did not exceed a deflection of 10 deg. The upper end of the chute was tangent to the curve, to allow the joints to be made up straight. The lower end of the chute was so curved as to allow the pipe to slide off into the trench without straining the joints. Platforms for workmen, making joints, were provided near the top of the giraffe. The giraffe was a complete success in every respect. There was no movement due to wave action, and during rough weather it was not necessary to lower the pipe and pick it up later with the accompanying undesirable movement of the joints. The contractor has applied for a patent on this apparatus.

The dredge preceded the pipe layer by only a short distance, digging a trench 5 ft. deep, about 10 ft. wide at the top and perhaps 5 ft. wide at the bottom. The dredging was done with an orange-peel bucket. The material was deposited on the bottom at one side of the trench and later replaced in the trench. A large lighter was kept beside the pipe-laying chute and placed the successive sections of pipe in position for jointing. It

also moved the giraffe by lifting the front end and dragging it ahead as each section of pipe was laid.

Laying the Pipe. The approaches to the submarine line having been laid by ordinary land methods to a half-tide point, and the dredge having completed something over 100 ft. of trenching at high tide, the giraffe was set in position about 50 ft. away from the land end of the pipe. It was

THE GIRAFFE.

found that some time could be saved by jointing two pieces of pipe on the deck of the lighter and hoisting the two pieces as a unit to the pipe-laying chute. This was made possible by the presence of the large and powerful lighter with an 80-ft. boom. Furthermore, the lighter by this method could move the giraffe 24 ft. at each shift.

Two pieces of pipe were placed in the chute and the lead joints were poured and caulked. The pipe after sliding down the chute was then scooted ashore. This operation is related to the use of a cable way, with the whip from the boom forming the cable and the pipe hanging from a snatch block riding on the whip. By this method, the end of the pipe was

carried toward shore as successive pieces of pipe were joined in the chute until the end of the submarine pipe was 6 ft. from the land pipe. This opening was left to allow a plug to be leaded in the end of the submarine line for testing purposes. It was also helpful to allow the entire line to be laid and back-filled in order that any settlement that took place could occur before the ends were completed. From this point, the pipe laying consisted of adding successive lengths to the line in the chute and pulling the giraffe along.

Time Required. The work was started on June 10 and completed on September 18, making 100 days of elapsed time and averaging 85 ft. of pipe daily. Laying the 12-in. pipe required 17 working days in 31 elapsed days with an average of 100 ft. daily for working days and 60 ft. daily for elapsed days. The best day's work was 168 ft.

Laying the 8-in. pipe required 30 working days and 41 days of elapsed time with an average of 222 ft. daily for working days and 162 ft. daily for elapsed days. The best day's work was 408 ft.

Testing. The specifications required that the leakage in the line should not exceed 4 gal. per linear foot of pipe joint per 24 hours at 150 lb. per sq. in. pressure. For the 12-in. line the leakage worked out to be 1.67 g.p.m. The first test was made on a Saturday and showed 1.83 g.p.m. On Monday morning a second test showed 1.33 g.p.m. and on Tuesday the leakage was 1.19 g.p.m. This progressive tightening of the line confirmed previous experience.

For the 8-in. line, the allowable leakage worked out to be 4.6 g.p.m. The test was made one afternoon and showed a leakage of 1 g.p.m. A second test an hour later showed no leakage. The hand pump used in testing held the pressure gage at about 150 lb. per sq. in. with no movement. A gate was then closed between the pump, and the line and the gage read 152 lb. per sq. in. It was left in this condition at the end of the day's work and on arrival the next morning on the job, it was found that the gage read 105 lb. per sq. in. Thus, it appeared that the line was bottle tight, a somewhat remarkable showing for a water main of this type.

Cost. On the 12-in. line, 170 ft. of foundation cost $3 263 or $19 per linear foot. The 377 ft. of 12-in. pipe laid by land methods on the flats between high water and mean tide cost $2 473 or $6.60 per linear foot. The 1 820 ft. of 12-in. submarine line exclusive of foundation cost $35 050, or about $19 per linear foot.

The following tabular statement shows the details of the above figures.

COST OF 12-IN. SUBMARINE LINE.

	1 820 ft. 12-in. Submarine Line.	377 ft. 12-in. Line on Flats.	170 ft. Pile and Cap Foundation.	2 197 ft. Total.
Cost of pipe	$7 252	$1 097	.....	$8 349
Labor and rent of equipment	24 476	1 208	$1 560	27 244
Other materials and supplies	1 659	72	1 559	3 290
Engineering and overhead	1 663	96	144	1 903
Total	$35 050	$2 473	$3 263	$40 786
Cost per foot	$19.25	$6.57	$19.20	$18.50

The 8-in. line cost $68 705, or $10.30 per linear foot. The details of cost are shown in the following schedule:

COST OF 6 660 FT. OF 8-IN. SUBMARINE PIPE.

Type of pipe.	Length. Ft.	Cost.	Cost per ft.
New flexible joint pipe	5 832	$12 830	$2.20
Old flexible joint pipe	828	1 429	1.72
Total pipe	6 660	$14 259	$2.14

COST OF 6 660 FT. OF 8-IN. SUBMARINE LINE.

	Cost.	Cost per ft.
Cost of pipe	$14 259	$2.14
Labor and rent of equipment	51 465	7.70
Other materials and supplies	451	.07
Engineering and overhead	2 530	.39
Total	$68 705	$10.30

Raymond F. Bennett, President of the Bennett Contracting Corporation, had personal charge of the execution of this work. Roy H. Beattie, was Consulting Engineer, and Eben L. Parrott was inspector of Construction. The author was Engineer for the Portland Water District.

COPPER AND HEALTH.

BY WM. G. SCHNEIDER.*

[*Read September 25, 1930.*]

The effect of copper on health has been the subject of a great deal of experimental work during the past century. When one considers the limited research facilities and background of knowledge available twenty-five years ago, it is surprising that physicians and medical research workers were able to understand so well the functions of the various organs of the human body and the effects of outside influences upon the human system.

Much progress has recently been made in that branch of medical science in which have been studied the underlying causes responsible for keeping the human system healthy or for causing disease. The laboratory facilities available to research workers in this field are now so far ahead of equipment of only a few years ago that it is difficult to imagine how men like Pasteur and workers following him could obtain any results at all. That they did, reflects greatly to their credit and testifies to the zeal with which they delved into little understood problems.

With reference to the effect of copper upon health recent researches confirm Pasteur's findings, an extract from which follows:

> In regard to the toxicity of copper salts, it may be said it is almost impossible to take a dose large enough to produce death, both from their horrible taste and from the violent vomiting which they produce. In small quantities the taste is not perceptible, and the salts are not only tolerated but absorbed. Workers in copper are often completely saturated with the metal, but do not suffer from it. Experiments on animal and human subjects have never given a worse result than vomiting or a temporary fit of colic. Copper normally exists in the human body. It gains entrance from various foods and drinks in the absence of all adulteration. It accumulates to a certain extent but injury from this accumulation is unknown.

Analyses of common foods show that they all contain copper in appreciable quantities; so that copper is taken into the human system as Pasteur states "in the absence of all adulteration." Some of the foods, listed in the accompanying table contain more copper than domestic drinking waters that have been called to the author's attention because of their copper content.

From the values listed in the table, it is apparent that copper is taken into the system daily with the foods we eat. A minute quantity of the metal is retained as a normal constituent in the body; the excess is excreted.

*Copper & Brass Research Association, New York, N. Y.

AMOUNT OF METALLIC COPPER IN FOOD SUBSTANCES.

	Milligrams per kilogram.		Milligrams per kilogram.
Almonds	23 to 37	Leeks	49 to 92
Barley	10 to 70	Lentils	110 to 150
Bean	trace	Liver, beef	51
Blood, ox	up to 5.6	Liver, calf	48
Brandy	1 to 8	Liver, ox	51
Buckwheat	150 to 160	Liver, sheep	33
Cocoa, pure, free from husk	47	Milk, cow	1.6
Cocoa, containing sugar and starch	58	Oatmeal	1.4
Crabs	20	Oats	40 to 200
Cucumbers	45	Oysters	2 000
Currants	8	Peaches	5
Duck, wild	8	Pears	4.2
Eggs, yolk	5.6	Peas	13 to 110
Eggs, white	7.2	Potatoes	2.8
Figs	1 to 19	Raisins	3
Flour	1.2	Rye	10 to 30
Grapes	1 to 6	Strawberries	8
Kidney	3 to 8	Wheat, summer	190 to 230
		Wheat, winter	200 to 800

Early Researches. Before reviewing the more recent researches on copper and health, it may be well to present some of the results and conclusions arrived at by earlier workers.

Filehne[1] "testing the effect of cupratin, made by heating sodium albuminate with copper sulphate, found that large doses given to cats and dogs produced vomiting, but no pathologic alterations in the liver could be discovered. Neither did an anemia develop. About 98 per cent. of the copper was eliminated in the feces." Tschirch[2] and Brandel[3] reached a similar conclusion.

In 1918 Huber[4] studied the effect of the copper salts of amino acids. "These compounds were given to guinea pigs by various methods — subcutaneously, intramuscularly and by mouth. In the chronically poisoned animals the results were entirely negative."

"Filehne[1] concluded from experiments with copper proteid that an amount equivalent to 0.5 grams of copper per day (500 milligrams per day) would produce no notable result in an adult."

Buck's "Handbook of Medical Sciences" states:

Contrary to the earlier teachings, recent observations tend to the view that there is no chronic copper poisoning, etc. According to this view the long continued ingestion of minute doses of copper by the stomach and the long exposure to absorption in handling and working the metal, are not capable of producing systematic poisoning. This view is based largely upon the negative results obtained in feeding experiments with man and the lower animals, and in the therapeutic use of copper salts.

"Galippe[5] had all of the foods which were used in his family for fourteen months cooked in copper vessels and reported that no trouble was experienced."

Pasteur states:

Copper normally exists in the human body. It gains entrance from various foods and drinks in the absence of all adulteration. It accumulates to a certain extent, but injury from this accumulation is unknown. In the samples submitted, copper exists to an extent varying between 16 and 45 milligrams per kilogram. . . . The quantity found does not constitute a danger to health.

Kraemer[6] speaking of the use of copper as a biochemical method to remove typhoid organisms from water states:

While exceedingly minute quantities of copper in solution are toxic to certain unicellular organisms, as bacteria, it is safe to assume that the higher plants and animals, including man, are unaffected by solutions containing the same or even larger amounts of copper. There being a number of factors which tend to eliminate copper from its solutions, it is hardly likely that there would be any copper in solution by the time the water from a reservoir reached the consumer if the treatment of the reservoir were in competent hands. Many plants contain relatively large quantities of copper, and when these are used as food some of the copper is taken up by the animal organism, but there are no records of any ill effects from copper so consumed.

Recent Researches. As interesting as are these results obtained some years ago, it is the recent researches that must be looked to for confirmation of the fact that copper is not injurious to health.

Thresh[7] in England concluded after a thorough investigation "that practically all waters take up traces of copper if allowed to stand sufficiently long therewith, but that under all ordinary circumstances the amount taken up is far too small to endanger health."

In 1927 Mallory[8] in a paper read before this Association, when referring to the use of brass pipe* for carrying water in homes, states, "So far, I have taken the ground that there is no evidence against this use, ..."

Flinn and von Glahn[9], working under the general supervision of Jobling, report findings that are of particular interest because they refute Mallory's theory that copper is the etiological agent of hemochromatosis, a disease of man characterized by pigmentation of the liver and increase in the connective tissue of the portal area of this organ (cirrhosis).

Extracts from the papers by Flinn and von Glahn should be of sufficient interest to be quoted at length.

The question as to whether or not the amount of copper found in our food and drinking water have any ill effects on the human organs, causing chronic diseases, is important to the average household, because of the increasing use of copper and its alloys in our homes.

Early investigators have not been uniform in their opinions, but the

*Author's Note: Presumably including copper pipe.

weight of evidence was that copper was not a harmful substance in the amounts that occurred in our food and drinking water.

Mallory, a pathologist who has been interested for some time in the subject of cirrhosis of the liver, came to the conclusion that copper might be the underlying cause of the comparatively rare disease known as hemochromatosis which has generally been found among men of middle age. He arrived at this conclusion from the fact that there seemed, at the time he made his observation, a sudden increase in the number of cases showing this pathologic lesion on autopsy. As a general thing, a history of the cases revealed the fact they had been accustomed to drinking alcoholic beverages sold since prohibition came into effect. An analysis of many samples of bootleg liquors sold in the city of Boston revealed the presence of copper in larger amounts than had been suspected, and it was felt that it had been dissolved from the copper coils during distilling of the crude liquors.

About the time these cases appeared in the Boston City Hospital, similar increases in cases in other hospitals in different cities were noted, but the number soon dropped to the normal level, at which one or two cases occur a year. This disease is comparatively rare, and Mallory only reports twenty cases.

In an attempt to show that the pigmentation of the liver associated with hemochromatosis was due to copper, rabbits were fed copper acetate for months and, after an examination of the liver, he came to the conclusion that "chronic poisoning with the salts of copper produced in the livers of rabbits in six months to a year, a change comparable in many ways with those found in the liver in a chronic disease in man known as 'hemochromatosis.'" He felt justified, therefore, in saying that chronic copper poisoning apparently was the causative agent of this disease in man.

Mallory's finding was contrary to the general concensus of investigators. The Departments of Industrial Hygiene and Pathology of Columbia University, therefore, undertook jointly an investigation of the question of the effects of copper on the human system. Some of their findings, as reported by Flinn and von Glahn, indicate that the conclusions that Mallory had drawn from his rabbits may have been founded on a wrong hypothesis.

Studies by Flinn and von Glahn. Flinn and von Glahn examined twenty specimens of human livers obtained from routine necropsies, in addition to other specimens obtained from copper workers. It was found that the copper content of these livers varied from 2.40 to 12.42 milligrams per kilogram of tissue, and what seems particularly interesting, that the copper content of the livers of the copper workers was close to the minimum. Livers of numerous animals were also examined, and all were found to contain copper, the amounts varying with the animal.

Flinn and von Glahn next tried to determine whether feeding copper or its compounds to animals was responsible for the pigmentation of the liver. Rabbits, rats and guinea pigs were used in their work, and definite amounts of the metal were fed to them, so that the exact exposure of the animal was known at all times. In this way it was shown by an analysis of the organs when the animal was killed, or died, that practically all the metal was eliminated. An examination of the various organs showed that while they might contain very small quantities of the metal, the liver was the main storage place of copper retained in the body. Work reported by

Flinn and Inouye[10] shows that almost all the copper ingested by the animal is eliminated in the stools.

The investigators at Columbia recognized that the control rabbit which had not been exposed to copper often showed the same lesions that were found in the exposed animal, and that for this reason wrong conclusions may be drawn. For this reason, they took particular care to examine normal rabbits kept under exactly the same conditions as to food and environment as the exposed animals, the only difference being that they were not fed copper.

The rabbits were divided into groups and fed different salts of copper as well as varying amounts. The animals received a standard diet, consisting of unrestricted quantities of hay and oats, with carrots and cabbage on alternate days. It seemed of interest to determine whether the acid radicle in the copper salts were of importance in influencing the deposition of the pigment. With this in view rabbits were given 100 milligrams of sodium acetate daily in chopped cabbage, along with their regular diet.

The result of the sodium acetate experiment raised the question of possible occurrence of pigment in the liver cells without the intervention of copper, and the investigators naturally turned to the diet. An examination of the standard diet suggested carrots as the most probable source of the pigment.

A number of rabbits were operated on, and a piece of the liver was removed for histological examination. Pigmentation and similar conditions were found in the livers of these unexposed animals similar to those noticed in the rabbits that had been fed copper and sodium acetate.

A number of the rabbits from which a specimen of liver had been removed were kept on a strict carrot diet. An examination of the animals showed an increase in the amount of pigment for four weeks; later there was no increase even when the animals were kept on carrots exclusively for 19 weeks. However, pigmentation greatly exceeded in amount that which existed in the liver of any control animal.

Animals kept exclusively on carrots were fed copper to see if a combination of copper with a carrot diet would produce even greater deposits. The pigment in the liver was definitely increased but no difference could be detected in the amount of connective tissue in the portal area.

Similar experiments, conducted with white and yellow turnips, showed that, compared with that present in the liver removed before the special diet was begun, the pigment was increased. This increase was not striking in either of the turnip diets. It did not exceed that found in the liver of the rabbits fed on carrots alone for one week and was not nearly so abundant as in the livers of rabbits fed on carrots for two weeks or longer.

All the experiments carried out by these investigators made it apparent that copper is not the cause of pigment deposition in the liver of the rabbit, since the same change is produced when sodium acetate is given with the standard diet. Furthermore, when rabbits are fed on a diet of carrots exclusively, the deposition of pigment occurs with greater rapidity than with copper or its compounds and the standard diet. The changes resulting in the livers of carrot-fed animals are identical in every way with those seen following doses of copper, and in animals given comparable doses of sodium acetate. On a diet of peeled turnips, pigment is deposited in the liver of the rabbit, though more slowly than with carrots.

In none of the rabbits given copper could a definite cirrhosis be proved. It is true that in some of the portal areas there appeared to be a slight increase in the number of connective-tissue cells. This also was readily made

out in the sodium-acetate fed animals and in those on a diet of carrots. The increased connective tissue was so slight that one would hesitate to make a diagnosis of cirrhosis. Even if it might, in the opinion of some, be considered a cirrhosis, its occurrence in the livers of the animals given sodium acetate as well as in those on a diet of carrots, would exclude copper as the etiological factor. Regarding the nature of the pigment, nothing definite can be said at the present time. Concerning its source the evidence indicates that it is of exogenous origin, for it is found in great abundance in rabbits fed upon carrots only, and in lesser amounts in those on a diet of turnips.

The conclusions of the workers at Columbia are:

That copper, or its compounds, does not cause the deposition of pigment in the liver of rabbits, guinea pigs or rats. Neither does it produce a cirrhosis in these animals.

That spontaneous deposition of pigment occurs frequently in the livers of normal rabbits on the usual laboratory diet.

That a diet of carrots exclusively will produce pigment deposition in the livers of rabbits in every way identical with that ascribed to copper.

That the pigment deposited in the livers of rabbits is probably of exogenous origin.

With these conclusions supported by the carefully controlled work of Flinn and von Glahn, the theory of Mallory that copper is the etiological agent of hemochromatosis appears to be founded on a wrong hypothesis, for he bases his theory on observations of pigmentation in the livers of animals. This pigment has now been shown to be due to exogenous origin.

Beneficial Effects of Copper. According to present evidence, the quantities of copper that are found in our food and drinking water will not injure any human organ. In fact, evidence is accumulating showing that small amounts have a beneficial effect on the blood in cases of anemia.

In 1929, the Iowa Agricultural Experiment Station issued Leaflet 126 on "Fattening Calves" in which the following is stated:

Recent investigations have shown quite clearly that copper fed in the form of copper sulphate or blue vitriol is of significance in animal nutrition, particularly from the standpoint of making it possible for the iron to be properly assimilated. The question then arises as to whether or not the incorporation of a little copper sulphate with the minerals is a good thing.

Other feeding tests with which the author is familiar have shown that copper carbonate regularly included in the feed has resulted in healthier animals, better yields, and has in every way proved beneficial.

McHargue[11] of the Kentucky Agricultural Experimental Station, as a result of his experiments states in one of his articles:

In a previous report the writer has demonstrated that small amounts of copper are associated with substances that contain the fatsoluble A factor. For example, the protein matter in normal butter made from whole cream, when separated from the butter fat, was found to contain considerable copper. Copper is also a normal constituent of the yolk of eggs, the germs of seeds, and the livers of animals. The occurrence of copper in Kentucky blue grass and other substances rich in the vitamin A factor suggests the

possibility of an important biological function for this element in the normal growth of plants and animals.

The Wisconsin Experiment Station recently issued Bulletin 410 in which is shown that copper and iron cure thumps in suckling pigs. From this bulletin it is noted that thousands of suckling pigs annually suffer from anemia, commonly referred to as thumps.

The symptoms are a low hemoglobin content of the blood, loss of appetite, depressed growth, lack of vigor and activity, quickened breathing in later stages; and upon post mortem examination the mucous membranes are pale, the liver mottled, the heart enlarged and the abdominal and lung cavities contain an abnormal quantity of fluid.

The Wisconsin scientists found the cause of this anemia to be a lack of iron. They discovered further, that despite a plentiful supply of iron in the feed, the anemic condition continued until a small amount of copper was added. It was found that solid feed should be taken by many of the new arrivals within three or four weeks and that this feed should contain copper and iron. So far, according to the bulletin, the only way to overcome thumps (anemia) in suckling pigs before they can be induced to eat grain or root in the dirt outside (which contains iron and copper), is to feed each pig daily 60 milligrams of copper sulphate and 25 milligrams of iron chloride.

Copper is an essential factor in the diet to keep the blood red and the body vigorous, a group of University of Wisconsin chemists headed by Hart,[12] announced recently at the meeting of the American Society of Biological Chemists.

Copper may become acknowledged as one of the more essential requisites in human nutrition and livestock feeding. The Wisconsin experiments indicate that it exerts a remarkable influence on anemia in rats, a disease similar to anemia in children who have been fed exclusively on milk. The malady in both rat and child is caused by a deficiency of hemoglobin in the blood stream.

A shortage of iron has been credited with being responsible for the disorder, and, although iron compounds are still limiting factors, their effectiveness, according to the Wisconsin investigators, depends on the presence or absence of copper. The Wisconsin investigations covered four years, and Dr. Hart was assisted by his colleagues, Drs. H. Steenbock, C. A. Elvehjem and J. Waddell.[12]

Because milk is low in iron, and hemoglobin is rich in the mineral, it has always been assumed that the way to correct anemia was to add iron to the milk.

In the case of animals, this plan proved ineffective. The daily feeding of iron, administered as chloride, sulphate, acetate, citrate or phosphate, all prepared from pure iron wire, did not check the decline in the hemoglobin content of the blood. Rats suffering from anemia were not improved.

On the other hand, when a supply of iron was obtained by feeding dried liver, or the ash of dried liver, corn or lettuce, the hemoglobin was raised

to normal, and the stricken rats were immediately restored to health. In ashing the food-stuffs, the investigators noted a pale, bluish color, the typical hue produced when copper compounds are burned. Observation of this peculiar color, in addition to the fact that copper is known to be present in the respiratory pigment, hemocyanin, of certain crustacea, led the chemists to use copper sulphate as a supplement to pure ferric chloride in the whole milk diet.

Striking cures resulted. Rats, so anemic that their days appeared to be numbered, recovered immediately, and the hemoglobin in their blood was brought to normal.

"What about pernicious anemia in man?" the chemists asked. Patients suffering with anemia have been told to eat liver, advice which has evidently made a wide impression, judging from the rise in price of what was once "poor man's meat." However, some sufferers find liver unpalatable, especially when eaten in large quantities. Scientists at Harvard University have prepared a liver extract which has proved exceedingly efficacious in abating the disease. In the Wisconsin experiments, this product was ashed and fed to anemic rats. When fortified with ferric chloride, it also proved effective in correcting the ailment. Thus this product which has been most successful in treating man corrected the deficiency in rats.

Copper's rôle in plant and animal tissues is not clearly understood. Copper is found in milk, in small quantities. Its function in producing hemoglobin is, as Hart states, unknown. Hemoglobin may not contain copper, at least no evidence to the contrary has yet been produced. In this connection, copper may act as a catalyzer, an agent which starts a reaction without itself entering into it. It may promote the building of hemoglobin. Iron functions in a similar manner in the production of chlorophyll, the green pigment of vegetation, although it is not a constituent of the chlorophyll molecule.

Experiments with the use of copper in the diets of anemic patients will be undertaken in the near future at certain leading hospitals. If this inorganic substance plays the part in the human system that it does in the life of white rats, nutritionists will probably give as much consideration to the copper content of food-stuffs as is now paid to some other elements, such as phosphorus, calcium and iodine. Future experiments at Wisconsin will also approach the problem from this standpoint, as the copper content of animal feeds is known to vary widely.

Research on the effect of copper on health was conducted by Polson[13] at the University of Manchester and Leeds. His findings confirmed those of Flinn and von Glahn that copper was not detrimental to health. Commenting on his experiments Polson says:

These experiments are claimed to be a fair repetition of those of Mallory, Parker and Nye.[14] The same range of dosage was used and the experiments lasted for a longer time. The longest experiment of their series was concluded at 11½ months, the average duration of the present experiments. In spite of this, neither cirrhosis nor pigmentation of the liver was produced.

As in the experiments of Flinn and von Glahn at Columbia, Polson found that such pigmentation of the liver as was observed was due to the diet and could be directly attributed to carrots, turnips and mangel-wurzels.

So far as the author knows, the latest research on this subject has been completed by the Prussian Hygienic Institute for Water, Soil and Air at Berlin. The president and medical adviser state (Translation):

> Where the quantity of copper in solution is measureable in milligrams per liter (p.p.m.) health will not be affected. However it is possible that where the copper content exceeds say from 3 to 5 milligrams per liter (p.p.m.) that the taste (of the water) may be adversely affected. Only larger amounts of copper in solution measurable in decigrams (per liter) and upward (hundreds of parts per million) would be detrimental to health.

It is stated in this German report that considerable doubt existed as to what effect copper would have on health and that on this account the research was undertaken and the question definitely settled.

As a result of these researches it can be stated with assurance that proper installations using copper, brass or other copper alloys where copper is the major constituent are absolutely safe for the conveying of water used in the home.

Copper in Water. As a matter of interest, the copper content of some of the more highly corrosive waters will be briefly mentioned.

Attention is invited to the paper on this subject presented before this Association by Clark[15] who found the average copper content of "running water" samples to be not greater than 0.150 p.p.m., while "standing water" samples contained about 0.5 p.p.m.

It appears from all data perused that only when the quantity of copper taken into the human system exceeds 100 milligrams per day may it be injurious. Clark has estimated that it would require more than 54 gallons of water with a high copper content of 0.5 p.p.m. to exceed the allowable daily dose of copper.

English authorities state "that each individual takes into his body daily 20 milligrams of copper and that so long as the total quantity of copper ingested does not exceed 100 milligrams daily there can be no question of injury to health." The value of 20 milligrams includes the copper in water and all other substances consumed.

Thresh in England has given much information on the copper content of various water. Clark in his paper has quoted Thresh's work which shows copper contents varying from zero in deep well water to two p.p.m. in very pure distilled water with zero hardness.

Copper in the form of copper sulphate is used to rid reservoirs of undesirable microscopic organisms. Hale and Muer report the addition to water of 0.12 p.p.m. of copper based on total reservoir volume. This water, after passing through about thirty miles of water mains, contained about

0.06 p.p.m. of copper. In general, copper sulphate treatment of water supplies is safe as regards the amount of copper added to it and its effect on health.

Conclusions. From the foregoing analysis of the problem, the author believes that it is apparent:

1. That the copper content of domestic drinking water after passing through copper or brass pipe or tubing, even if a slight amount of copper is taken into solution, is not harmful to health. It may indeed be beneficial.

2. That all water supplies intended for domestic use after passing through a proper installation of copper or brass pipe or tubing will contain but a small percentage of the permissible copper content, if any at all.

3. That the permissible copper content of domestic water based on a consumption of one gallon of water a day should apparently not be greater than 20 p.p.m.

4. That it is unlikely that health will be injured by copper because where the copper content is above 5 p.p.m. the taste of the water will generally be so disagreeable that it will be virtually impossible to drink it.

5. That no anxiety need be felt about a proper installation of copper or brass pipe or tubing, because it has been shown that with acid water having a pH value of about 6.5, the copper content is generally only about 0.5 p.p.m. even after standing in the pipe lines for an appreciable length of time.

6. That the treatment of reservoirs with copper sulphate to rid them of undesirable microscopic growths has no injurious effect on health.

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HOW SMALL CAST-IRON PIPE IS MADE AND USED.

BY J. R. McWANE.*

[*Read September 23, 1930.*]

In the early days, a comparatively large amount of small cast-iron pipe was used. In the older cities of this country, there are notable proofs of this. Baltimore had small cast-iron pipe services, the connection with the mains being made with a ferrule. This rigid connection, under increased strains of traffic, was not satisfactory, but the small cast-iron lines themselves were satisfactory. In Louisville, Ky., $\frac{3}{4}$-in. cast-iron pipe with threaded male and female ends, has recently been taken up. This material, after more than a half century of service, was still in good condition. The lower cost of wrought-iron and steel pipe and the greater convenience in their use, as compared with small cast-iron pipe, however, made such inroads on the business that until recent years the quantity of small cast-iron pipe used in this country was negligible.

About ten years ago, the author conceived the idea of bringing small cast-iron pipe for underground pressure-service back into its own, and since that time considerable progress has been made in that direction.

Manufacture. All cast-iron pipe, including the smaller sizes, was originally made by the horizontal method, employing a dry sand core and one or more chaplets to keep the core central. In the larger sizes, with the increased demand for longer lengths, this horizontal system was abandoned and the vertical method became almost the universal practice. Sporadic attempts were made to cast the smaller sizes in this way, but the cost proved prohibitive.

The improvements in foundry practice in recent years have made possible the production of small cast-iron pipe at a cost comparable with that of steel and wrought-iron pipe. These improvements cover sand handling, core making, machine molding, mechanical ramming, multiple-lip ladle-casting and, most important of all, mechanical devices for centering the core in the mold and compensating for the core movement that takes place in casting. These improvements lend themselves to the horizontal method of manufacture. This process is much more economical than the vertical plan. When cast-iron pipe is cast vertically, it is necessary to dry both the molds and the cores. Aside from the expense of this operation, the necessity for doing this retards production and still further increases cost.

The requirement of the specifications of the American Water Works Association for sand-cast pipe, to the effect that all pipe shall be cast vertically in dry sand molds, has led to the erroneous conclusion that there is virtue *per se* in the drying. The truth of the matter, in the author's opinion,

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is that the drying of molds and cores for thin castings, where strength is important, is only a necessary evil. The drying not only does not add to the quality of the product but is actually a detriment to the casting. It is recognized by those skilled in the art of founding that a casting made in green sand is stronger than one made in dry sand, for the reason that the contact of the molten iron with the damp mold causes more sudden cooling than a dry mold and a consequent closer-grain casting. Nature has provided that there is just a sufficient quantity of moisture in what is known in foundry circles as green sand to cause the iron to cool with sufficient rapidity to close the grain, but not sufficiently fast to produce a decidedly chilling effect. The result is a casting that is strong and machinable.

Another advantage of the horizontal method of casting is that it renders possible the making of any special shapes, such as octagons or hexagons at the base of the bells and spigots to screw together, bosses or collars for tapping, and permanent lettering for identifying the name of the manufacturer and the date of production, all of which are very important. For these reasons, almost all the small cast-iron pipe for underground use is made by the horizontal method.

Short Lengths Factory Connected. Small cast-iron pipe is necessarily made in short lengths. In the 2-in. size it has been made largely in 5- and 6-ft. lengths, though recent experiments have demonstrated that it can be cast horizontally as long as 9 ft., and quantities will doubtless be produced in the near future in this length. The tendency in all kinds of piping is to reduce, so far as possible, the amount of field work. For this reason it has been found advisable to do the maximum practicable jointing at the factory and ship the pipe in as long lengths as possible. Most 2-in. pipe at the present time is being shipped in 18-ft. lengths, though in special cases it is sent out in 5- or 6-ft. lengths.

It is the judgment of the author that the safest and most economical method of making up these intermediate factory joints is to use the standard American Briggs thread. The pipes are cast with male and female ends, and the practice found most satisfactory is to use the thread of the size next larger than the nominal diameter of the pipe. That is to say, on a $1\frac{1}{2}$-in. pipe a 2-in. thread is used, on a 2-in. pipe a $2\frac{1}{2}$-in. thread, and so on. By doing this, there is sufficient stock to make the wall at the base of the thread stronger than the body of the pipe, instead of the base of the thread being the weakest point, as is the case when the thread is the same as the nominal diameter.

The 18-ft. lengths, thus produced, may be screwed together in the field in the same way as ordinary steel pipe is assembled, or the ends of the 18-ft. lengths may be given the form of ordinary bell and spigot ends with a factory-made joint or an open bell in which any joint may be made to suit the user. Our experience has shown that the majority of users prefer a factory-made joint, in the smaller sizes, because the time required for making the joint in a small cast-iron pipe is practically as great as that required

for a larger size. The leading manufacturers of small cast-iron pipe for underground service recommend a flexible field joint, rather than a rigid threaded joint, though large quantities of 2-in. pipe are being used with 2½-in. threaded joints only, and sleeves for connecting with fittings.

Uses for Small Cast-iron Pipe. One of the largest cities in the United States has adopted 2-in. cast-iron pipe for services, the practice being to run the 2-in. pipe to the property line and diverge from there to the two lots. In beginning the use of cast iron for this service, the practice was to cut a 2-in. thread on a 2-in. pipe and to screw this into a 2-in. corporation cock. This was found unsatisfactory, because breakage was likely to occur at the base of the thread under the strains of settlement or traffic. This difficulty was overcome by providing a short bell at the outlet end of the corporation cock and caulking lead around the spigot end of the pipe. This gave a flexible connection with the full strength of the pipe, not weakened by the cutting of the thread. What is known as a bell brace has been developed for special use in connecting small cast-iron pipe to a main. This is nothing more than a braced adapter, the inlet end of which has a standard thread that can be screwed to a corporation cock having a similar standard thread and a bell with a factory-made joint in which to caulk the spigot end of the cast-iron pipe. This also gives a flexible connection.

One large user of 2-in. cast-iron pipe makes the connection to the main with a 1-in. gooseneck. The connection with the 2-in. pipe is made with a malleable increaser with 1-in. male thread on one end and 2½-in. thread on the other end. A 2½-in. collar is screwed to the outlet end and the 2½-in. thread of the cast-iron pipe is screwed into this collar, which completes the process of getting away from the main. It is claimed that, on the principle of the Venturi meter, an adequate flow of water is secured through this 1-in. gooseneck, especially as there are usually two connections of this kind, one at each end of the 2-in. line, thus securing circulation. Either the bell-brace principle or the gooseneck is a satisfactory method of connecting small cast-iron services with the main.

Cast-iron pipe 2 and 3 in. in diameter is being used more and more for small mains. It is usually assumed that these small mains are only temporary. In many cases, however, the expectations as to future growth are not realized, and the mains prove to be permanent. Apparently, it is being found that cast-iron pipe is satisfactory because it will give long service. If only temporary service is required, it can be taken up and relaid, so that there is no loss of capital investment.

Tapping bosses or collars that are cast on small cast-iron pipe mains make it possible to tap within a maximum distance of 3 ft. of any given point without the use of tapping saddles. Tie-in lines of cast-iron pipe are as long-lived as the mains themselves. Where the two-main system is adopted, experience has shown that the smaller sizes can be as small as 2 in. This has been found to be highly advantageous because of the increased circulation.

Quantities of small cast-iron pipe are used for irrigating golf courses. This type of pipe is being installed more and more in parks and cemeteries, and most large filtration plants that have been built in this country in recent years have used cast-iron pipe for laterals.

Hundreds of thousands of feet of 2- and 3-in. cast-iron pipe are being installed for gas lines where pressures range from 10 to 30 lb. per sq. in. or higher. The perfection of special joints, providing for expansion and contraction and deflection, has made the use of this material possible in this field.

The water-works man is interested in everything that goes into the streets. The digging up of streets and the consequent obstructions to traffic are rapidly becoming a serious problem, and it is believed that the pioneering that has been done in recent years in the manufacture of small cast-iron pipe is no small contribution to the solution of this problem.

HYDRAULIC SERVICE CHARACTERISTICS OF SMALL METALLIC PIPES.

BY G. M. FAIR*, M. C. WHIPPLE† AND C. Y. HSIAO.‡

[*Read September 23, 1930.*]

It is the purpose of this paper to present some of the information collected by the authors in a three-year study of the hydraulic service characteristics of small metallic pipes carrying a relatively soft eastern upland water after purification by coagulation and rapid sand-filtration.

The study was undertaken with a view to obtaining a continuous record during three years of the progressive changes in the hydraulic properties of present-day pipes, produced by the delivery of known quantities of water. In order to carry the tests as far as possible within the time available for the study, water was permitted to flow continuously through the pipes. Continuous flow, however, is not common in service lines and interior distribution systems in which the use of small pipes finds its most general application. In such pipe lines, there is an alternation of draft and quiescence, except in unusual cases. In view of this fact, it is not possible to express the information obtained in our study in terms of expected useful hydraulic life under normal service conditions. To permit such expression, it would have been necessary, in view of the small magnitude of hydraulic changes in the more resistant pipes, to extend the study over a period of time measured by the span of activity of one or more generations of man.

Our method of approach, however, did permit the determination of hydraulic characteristics on a definite service basis, namely quantities of water delivered or time of continuous service with reasonable and practically constant velocities of flow. This information has not been available, heretofore.

Observations of the changes in interior structure of the pipes were only incidental to the study and were confined to a visual examination of pipe interiors at the end of the test period. A critical analysis of hydraulic measurements, however, permitted an interpretation of hydraulic service effects in the form of roughening of the interior of the pipes and obstruction of their waterways. This interpretation we believe to be essentially new.

Seven different commercial pipe materials were included in our study, namely: copper, red brass, admiralty metal, galvanized wrought iron, galvanized steel, wrought iron and steel. These materials were selected as covering the best grades of metallic water pipes. Two sizes of pipe of each of these materials were employed: 1½-in. pipe and ¾-in. pipe, these sizes being chosen as representative of small and medium-sized service and interior distribution systems. There were two batteries of ¾-in. pipes of

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the seven materials, one carrying cold water, the other hot water. A single battery of 1½-in. pipes carried cold water.

Lay-out and Test Conditions. With the generous coöperation of the Cambridge Water Board, the study was conducted at the Cambridge Filter Plant. The pipes to be tested were furnished by the manufacturers from stock together with suitable couplings. The individual pipe lengths varied

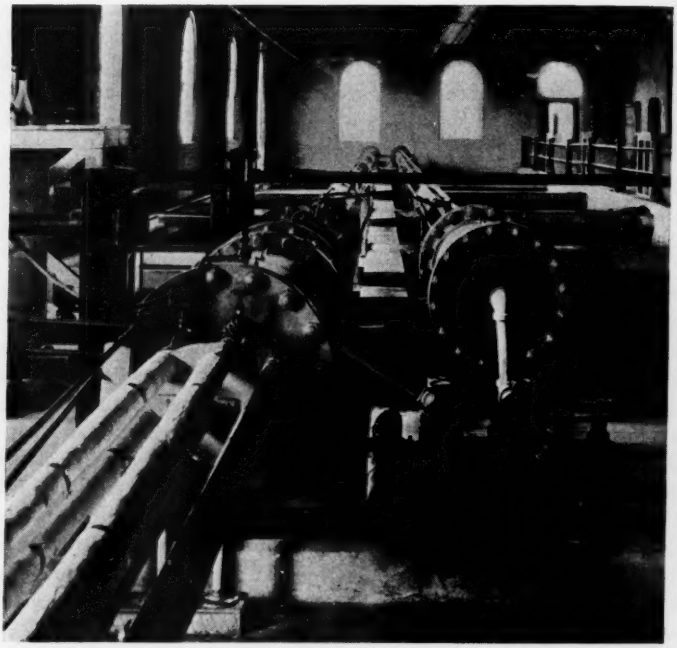


FIG. 1.— INSTALLATION OF TEST PIPES ON OPERATING FLOOR OF CAMBRIDGE FILTER PLANT.

Hot-water battery in foreground, two cold-water batteries in background.

from 12 to 20 ft. and were assembled into test runs of 100 ft., the pipe ends being carefully butted in order to insure continuous surfaces and to reduce galvanic corrosion due to differences in the composition of the pipes and their couplings. As shown in Figure 1, the three batteries of pipes (1½-in. cold water, ¾-in. cold water and ¾-in. hot water) were each composed of a common inlet drum, separate 100-ft. runs of the seven different pipe materials and a common outlet drum. Each pipe run was connected to its inlet and outlet drum by means of a short piece of rubber hose in order to prevent galvanic corrosion between the pipes and their connecting nipples on the drums. The drums served to distribute and collect the water passing through each battery of pipes.

The chemical composition of the different pipe materials, as furnished by the manufacturers, is shown in Table 1.

TABLE 1.— CHEMICAL COMPOSITION OF PIPE MATERIALS.

Material.	Percentage Composition.	Material.	Percentage Composition.
Copper	$Cu + Ag = 99.961$	Steel	$Mn = 0.35$ $P = 0.10$ $C = 0.07$ $S = 0.05$
Red Brass	$Cu = 84.63$ $Zn = 15.30$ $Pb = 0.02$ $Fe = 0.05$	Wrought Iron	$C = 0.03$ $Mn = 0.03$ $P = 0.19$ $S = 0.04$ $Si = 0.21$
Admiralty Metal	$Cu = 71.04$ $Zn = 27.76$ $Sn = 1.17$ $Pb = 0.02$ $Fe = 0.01$		

The water fed to the two cold-water batteries of pipes was supplied from the wash-water tank of the filter plant and represents Cambridge water before corrective treatment for corrosive properties by the addition of soda ash.* The hot-water feedline was taken from the pressure main of the plant and carried water that had been subjected to corrective treatment. The hot water, therefore, contained less carbon dioxide than the cold water and had a higher alkalinity and pH value but the same total hardness. The chemical composition of the water remained fairly constant throughout the period of study, as can be seen from the analytical results presented in Table 2. The temperature of the cold water varied seasonally from 36° to 77° F. The hot water was maintained by a thermostat at about 140° F. Fresh water passed through both cold- and hot-water pipes at all times. The water was not recirculated.

TABLE 2.— QUALITY OF COLD-WATER AND HOT-WATER SUPPLIES DURING PERIOD OF INVESTIGATION, APRIL, 1927 to NOVEMBER, 1929.

Period.	Turbidity. p.p.m.		Color. p.p.m.		Alkalinity. p.p.m.		CO_2 p.p.m.		pH.	
	Cold.	Hot.	Cold.	Hot.	Cold.	Hot.	Cold.	Hot.	Cold.	Hot.
April, 1927 to April, 1928	1—	1—	4	8	10.0	17.5	11.0	3.0	...	...
April, 1928 to April, 1929	1—	1—	3	5	13.0	22.0	6.0	1.0	6.1	7.0
April, 1929 to November, 1929	0	0	2	3	12.1	18.7	4.1	1.0	6.1	7.0

*Since completion of the tests the plant has substituted lime for soda ash.

Each battery of pipes was provided with a standard disk meter for measuring the quantity of water delivered to it. The meters on the two cold-water batteries had efficiencies of registration of practically 100 per cent. and showed little change with use. The hot-water meter, which was first provided with a copper disk, and later with one of hard rubber, gave some trouble because of the strain placed upon it by the high water-temperature. Its average efficiency during the study was probably between 85 and 95 per cent.

The service water and water for testing, the latter being taken from the pressure supply, were brought to the installation through separate lines and connected to the three batteries with the necessary valves. The discharge line from each outlet drum was arranged so that the water could be wasted into the filters during the service periods or delivered to the weighing tanks when the pipes were being tested.

The apparatus for making the hydraulic tests included suitable piezometer rings on each pipe, which could be connected to a differential mercury manometer, and a standard system of weighing tanks for determining the rate of flow of water. The mercury gage read to 0.001 ft. and had a working range of 0.38 to 29 ft. of water.

The pressure openings in the pipes consisted of four $\frac{1}{8}$-in. holes spaced 90 deg. apart. The holes were carefully drilled so as not to leave burrs on the inside of the pipe. To insure further against rough edges, the interior walls at the site of the pressure openings were smoothed gently by means of a round file. Piezometer rings of the usual design were sealed to the pipes with lead packing. Bronze rings were provided for the copper, red-brass and admiralty-metal pipes; cast-iron rings were employed on the others. The pressure openings were located at distances of 80 and 160 diameters from the drums for the $1\frac{1}{2}$-in. and $\frac{3}{4}$-in. pipes respectively, thus insuring steady flow throughout the test length of pipe. The distance between rings was approximately 80 ft. in each case.

The piezometer rings, pressure leads and the gage were provided with air cocks at all summits for the removal of entrapped air. The inlet drums were also equipped with air cocks and baffles, thus serving as traps for the removal of air during the test periods.

Experimental Procedure. The hydraulic properties of pipes are defined in general by their relative carrying capacity, or rate-of-discharge relative to their size and to their pressure loss per unit length. Specifically there enter into this relationship, in addition, the physical properties of the water, notably its density and viscosity, which are defined by its temperature, and the frictional character of the pipe walls, which is indicated by the material employed and its change with service. With the size and length of pipe known, therefore, experimental measurement of the hydraulic properties of different pipes after different intervals of service involves the determination of their rates of discharge for different pressure losses, the temperature of the water being noted at the same time.

With this in mind, the schedule of our investigations consisted briefly in determining the initial relative carrying capacity of each pipe, placing the pipes in service and, at intervals thereafter, again testing the pipes. The amount of water that had passed through each pipe previous to the time of testing was determined from the meter readings and hence, for each pipe, the progressive changes in relative carrying capacity could be correlated with the cumulative amount of water that had passed through it. A sufficient number of tests was run to establish for each pipe the trend of reduction in relative carrying capacity with service.

In establishing the relationship between loss-of-head and rate-of-discharge for each pipe, the line under test was first flushed at high velocity to remove the loosely-bound products of corrosion and deposition. At the same time the air cocks were opened and allowed to discharge until all air was removed from the system. One air cock on the inlet drum was also left open during testing. Water was then allowed to pass through the pipe, and beginning at the highest available flow, the pressure-loss and corresponding rate-of-discharge were determined over a sufficiently wide range to establish a good curve. The water temperature was obtained for each test, at the inlet drum and at the weighing tank.

Since a single meter was provided for a battery of pipes, it was necessary to calculate the amount delivered to the individual pipes. This was done by proportioning the total amount delivered to the battery between two successive test periods among the seven pipes on the basis of their average hydraulic properties, as determined by the two tests. The amount of water used during the test of a given pipe was credited to that line. The testing water was not the same as that delivered during service, particularly as regards the temperature factor in the hot-water battery. The amount added during testing, however, was relatively small compared with that delivered between tests. Hence it had little effect upon the final results.

Care was taken to keep the velocity approximately constant during the service periods. A velocity of one foot per second was chosen as consistent with conditions of flow found in practice without leading to excessive water-use in the tests; the velocity in the pipes of the hot-water group, however, was slightly less. Since the length of pipe between piezometer rings was close to 80 ft. in each case, the time of flow through the pipes was about 80 seconds.

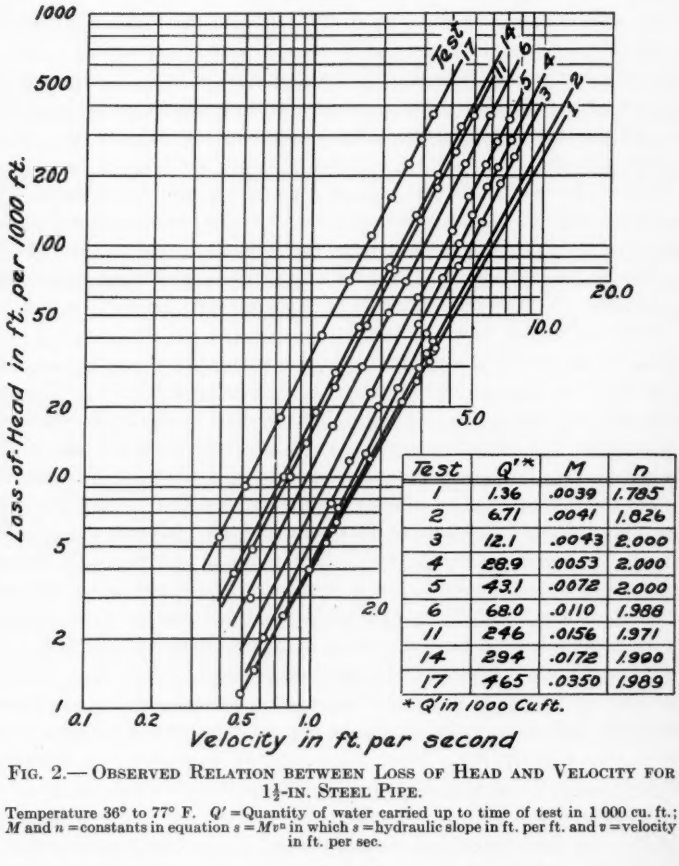
Nature of Experimental Determinations. In accordance with the experimental procedure adopted, the test records assembled for each pipe, after specific service periods, measured by the quantity of water passed, showed (1) the unit loss of head or hydraulic slope, (2) the rates of discharge or average velocity on the basis of original pipe diameter and (3) the water temperatures. The hydraulic slopes when plotted against velocities of flow on double-logarithmic paper, yielded a straight-line relationship between these factors in agreement with general experience and expressed by the well-known exponential equation for pipe flow:

$$s = M\, v^n$$

where s = hydraulic slope in ft. per ft.

v = velocity in ft. per sec.

M^* and n^* = variable constants determined respectively by the intercept of the line on the ordinate at $v = 1$ and by the slope of the line.



Test	Q'*	M	n
1	1.36	.0039	1.785
2	6.71	.0041	1.826
3	12.1	.0043	2.000
4	28.9	.0053	2.000
5	43.1	.0072	2.000
6	68.0	.0110	1.988
11	246	.0156	1.971
14	294	.0172	1.900
17	465	.0350	1.989

* Q' in 1000 Cu ft.

FIG. 2.— OBSERVED RELATION BETWEEN LOSS OF HEAD AND VELOCITY FOR 1½-IN. STEEL PIPE.

Temperature 36° to 77° F. Q' = Quantity of water carried up to time of test in 1 000 cu. ft.; M and n = constants in equation $s = Mv^n$ in which s = hydraulic slope in ft. per ft. and v = velocity in ft. per sec.

Typical curves are shown in Figure 2 for 1½-in. steel pipe. Without exception similar results were obtained for the entire series of tests on all the pipes. The hydraulic characteristics of each pipe after any service period was thus completely described, both graphically by the double-

*The exponential equation may be written also as follows:

$$\log s = \log M + n \log v$$

Hence for $v = 1$ ($\log v = 0$), $\log s = \log M$ ($s = M$),

and $\dfrac{d(\log s)}{d(\log v)} = n$

logarithmic plot and analytically by the substitution in the exponential equation of the values of M and n read from the plot.

This fundamental information, however, was not in a form in which it could be directly employed to express the service characteristics of the different pipes simply and comparatively. In order to do so, recourse had to be taken to more generalized measures, a theoretical consideration of which follows.

Generalized Measures of Service Characteristics.

The general exponential relation found to exist between hydraulic slope and velocity of flow is the basis of nearly all pipe-flow formulas. An examination of the best-known formula, the Chezy formula: $v = C\sqrt{r\,s}$, or its variate, the Darcy formula: $s = \frac{f}{d}\frac{v^2}{2g}$, (in which v and s are as before, r is the hydraulic radius in feet, d is the diameter in feet, g is the gravity constant and C and f* are coefficients), will show that this formula does not lend itself well to the establishment of a generalized measure of service characteristics.

According to the Chezy and Darcy formulas, s is proportional to v^2, r^{-1} or d^{-1} and C^{-2} or f. It is well known, however, that s does not always vary as v^2 and r^{-1} or d^{-1}, but is a function of v^n and r^{-m} or d^{-m}, where n and m are interdependent variables. In practice n is found to range from 1.70 to 2.00, and m varies from unity, when n equals 2.00, to somewhat higher values when n is less than this. The Chezy and Darcy formulas apply strictly, therefore, only in the special case when the value of n is 2.00. It follows that the coefficients C and f allow in part for inadequacies in the statement of velocity and diameter relations and cannot be employed satisfactorily as measures of differing or changing frictional characteristics of pipes. These frictional characteristics, commonly called roughness, are the cause for differences in hydraulic properties.

The Hazen-Williams Coefficient, C_w. Hazen and Williams have attempted to eliminate the inadequacies in the statement of velocity and diameter relations by writing the pipe-flow equation as follows:

$$v = C_w\, r^{0.63}\, s^{0.54}\, 0.001^{-0.04} \text{ or}$$
$$s = 3.02\, C_w^{-1.85}\, v^{1.85}\, r^{-1.17}$$

in which v, r and s are as before and C_w is a coefficient of the same general magnitude as Chezy's C. The exponents n and m of v and r, or d, respectively have the values 1.85 and 1.17. These are average values based on an analysis of a large number of experiments. Assigning to n and m average rather than extreme values, as done by Chezy and Darcy, therefore, reduces the influence of v and r, or d, upon the coefficient C_w and hence makes it more completely, although not perfectly, a measure of frictional characteristics.

*Since in a circular conduit $r = \frac{d}{4}$, $f = \frac{8g}{C^2}$.

Expressing the velocity v in terms of the rate of discharge Q (in cubic ft. per second) and the area $A = \frac{\pi d^2}{4}$ (in square feet), and the hydraulic radius r in terms of the diameter d, the Hazen-Williams equation becomes:

$$s = 4.75\ C_w^{-1.85}\ d^{-4.87}\ Q^{1.85}$$

The relative carrying capacity of a given pipe after different periods of service, or of two pipes of the same diameter but of different materials at any time, is then determined by the relation: $\frac{Q_1}{Q_2} = \frac{C_{w1}}{C_{w2}}$, the remaining terms in the equation yielding unit ratios. The value of C_w or of the ratio $\frac{C_{w1}}{C_{w2}}$, therefore, measures the relative carrying capacity of a pipe and can be employed as a generalized measure of service characteristics. In doing so, it must be remembered, however, that the Hazen-Williams formula is founded on the assumption that s varies on an average as $v^{1.85}$ and $r^{-1.17}$*; furthermore, that the formula does not allow for influences associated with variation of the physical character of the water as determined by its temperature. How the authors took account of these limitations will appear in the discussion of service characteristics as measured by the Hazen-Williams coefficient C_w.

The effect of water temperature on the hydraulics of municipal distribution systems, which are only subject to seasonal changes in the temperature of the water they carry, is not marked. In our tests the normal seasonal variation in water temperature from 36° to 77° F. caused a maximum difference of 12 per cent. in loss of head at a given velocity. The temperature factor is, therefore, commonly neglected without serious consequences in dealing with municipal distribution systems. Interior distribution systems, however, may carry either cold water or hot water, the range in temperature being from 36° to 140° F. or higher. The temperature effect, therefore, becomes appreciable. Thus we found a decrease in hydraulic slope of 29 per cent. for pipes carrying water at 140° F. as compared with water at 36° F.

Service Characteristics Measured by n and d_e/d. In order to develop generalized measures of service characteristics that would express more adequately the hydraulic differences between pipes of different materials or pipes after different periods of service, the authors proceeded from the general exponential equation $s = M\ v^n$.

As previously indicated, this equation was found to hold throughout the investigation, for old as well as new pipe. According to some observers the relationship between hydraulic slope and velocity is not constant at high velocities. Within practical limits, however, it appears to us to be an adequate expression of flow characteristics.

Starting with a value close to 1.75, n was found to increase with service.

*Dimensional analysis indicates that the sum of the exponents n and m of v and r, or d, respectively should yield a value of 3.00. In the Hazen-Williams formula, the value of the sum is 3.02.

In no case, however, did it exceed 2.00. The value of M was observed to decrease with service until n reached a value of 2.00; thereafter it increased without apparent upper limit. Changes in the values of these two factors with service are illustrated by the curves for the series of tests on 1½-in. steel pipe, shown in Figure 2.

Since n and M are both affected by changes in the pipe walls with service, it follows that pipe roughness must be measured in part by both these terms. According to dimensional analysis, the exponent, n, is an independent dimensionless number; M, however, is a function of certain other factors including pipe diameter (d), viscosity (μ) and density (ρ) of the water. The term M is also affected by n, since it represents the value of s when v is unity. As it stands, therefore, it is not an independent measure of roughness.

The nature of variation in M was studied by means of a series of carefully controlled hydraulic tests upon a number of glass and copper pipes. In these tests, pipe diameter, water temperature and velocity were varied over a range of sufficient magnitude to establish reliable curves of relationship between these various factors. The test values of n varied from 1.69 to 1.85. From the data obtained, the functional relation between M and the factors, d, ρ/μ and n, was found to have the following form:

$$M=\frac{k}{g}(\rho/\mu)^{n-2}\,d^{n-3}$$

where k is a variable constant and ρ, μ, d, n and g are as before.

Thus, M is determined by a variable constant, k, as well as by diameter, water temperature and the exponent, n. Examination of the variation in k revealed that it is a function of n alone. This relationship was determined* graphically to be:

$$k=32\left[1918\left(1.918-\frac{1}{n-1}\right)\right]^{1-n}$$

The above expressions for M and k were obtained from limited data; no claim is made as to their general applicability.

Since k is a function of n alone, M must be a function of the physical factors, d and ρ/μ, and of n, which may be determined graphically. It follows, therefore, that roughness must be measured by the value of n. For a smooth pipe, n has a value of 1.70 to 1.75; for rough pipe, n approaches 2.00, but never exceeds it. Hence, M reaches a constant value when n equals 2.00.

According to this reasoning, a given pipe has a maximum value of s (for the same rate of discharge, Q) when n reaches its upper limit of 2.00. This conclusion, however, is contrary to the facts; the data for a number of pipes tested, notably steel and wrought-iron pipes, show that M did not reach a constant value when n equalled 2.00, but increased as the pipe

*According to a later analysis, a better relationship is given by the expression

$$k=32\left[2140\left(0.8585-\frac{2-n}{n-1}\right)\right]^{1-n}$$

All calculations in this paper, however, are based upon the first formula.

continued in service, as indicated in Figure 2. Thus, it follows that roughness is not measured by n alone. An examination of the expression for M suggests that the only factor that can be affected by service, other than n, is the pipe diameter. This is in accordance with the fact that with service the waterway of pipes is gradually restricted by the deposition of bulky products of corrosion or by sediment. Only in rare cases will there be an increase in waterway by the wearing away of the metal without subsequent deposition. The change in pipe diameter with service, therefore, can be taken as a second measure of the variation in carrying capacity with service. The changed diameter, of course, is not generally a measurable physical quantity. The change may be quite irregular and is the result of corrosion, deposition of solids and similar activities. The net result, however, may be thought of as producing an "effective diameter," d_e, which is believed to be a new concept in the formulation of pipe flow.

The effective diameter, d_e, may be calculated directly from M, n, d and ρ/μ. The relationship can be shown to have the following form*:

$$d_e=[(k/g)\ (d^{2n}/M)\ (\rho/\mu)^{n-2}]^{1/n+3}$$

When d_e is introduced into the experimental equation, $s=Mv^n$, and v_e, calculated on the basis of reduced diameter, is substituted, M_e is found to remain practically constant at all times when $n=2.00$. By expressing the effective diameter, d_e, in terms of the original diameter, d, we thus obtain two dimensionless measures, n and d_e/d, of the hydraulic service characteristics of water pipes.

The progressive changes in relative carrying capacity may, therefore, be thought of as being produced by two factors: (1) the change in surface conditions as measured by n, which increases from about 1.75 to 2.00, and (2) the change in pipe diameter as measured by d_e/d. These two factors probably exert their influence on the hydraulics of pipes in two stages in the order given. In the case of small pipes, however, the stages may overlap.

It follows from this brief summary of theoretical considerations that the hydraulic service characteristics of small pipes may be measured: (1) approximately by the changes in the Hazen-Williams coefficient C_w; and (2) more closely by the changes in n and d_e/d. The results obtained by both these methods will be presented in the following sections of this paper.

*The exponential law, $s=Mv^n$, does not change when d_e is used in place of d, nor does the value of n change. That this is true, is readily shown by the following: Since $v=Q/A$, where A = area, we may write

$$s=M\frac{Q^n}{A^n}=M\left(\frac{4}{\pi d^2}\right)^n Q^n$$

Thus, the exponential relation between s and Q remains the same, no matter what diameter is used. The exponential law may now be written:

$$\log s=\log M+n\log v$$

Taking the differentials on both sides, and solving for n:

$$n=\frac{v}{s}\frac{ds}{dv}$$

But, $v=4Q/\pi d^2$ and $dv=\frac{4}{\pi}\frac{dQ}{d^2}$

By substitution, we get

$$n=\frac{Q}{s}\frac{ds}{dQ}$$

Thus, n is shown to be independent of diameter.

Service Characteristics as Measured by the Hazen-Williams Coefficient, C_w.

As previously noted, the Hazen-Williams formula is founded on the assumption that s varies as $v^{1.85}$ and $d^{-1.17}$ and that temperature effects are generally negligible. Since these assumptions hold only for average condi-

Table 3.— Changes in Hydraulic Characteristics with Service.
1½-in. Pipes.
Temperature: 36° to 77° F.
(Amount of water passed Q' in 1 000 cu. ft.; temperature t in ° F.)

Copper.						Red Brass.						Admiralty Metal.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
8.1	50	135	.0038	1.770	1.00	6.4	49	136	.0039	1.733	1.00	5.9	51	135	.0039	1.769	1.00
13.6	52	137	.0037	1.785	1.01	11.8	51	136	.0039	1.742	1.00	11.5	53	135	.0039	1.768	1.00
33.2	64	136	.0037	1.770	1.01	28.8	63	135	.0037	1.755	1.00	29.4	63	134	.0038	1.755	1.00
50.6	71	135	.0037	1.732	1.00	46.3	71	135	.0036	1.770	1.00	48.7	71	135	.0036	1.769	1.00
81.7	71	136	.0036	1.775	1.01	80.3	63	135	.0038	1.752	1.00	79.1	63	134	.0038	1.760	1.00
164.9	37	133	.0044	1.725	0.99	167	37	134	.0043	1.735	1.00	162	37	134	.0042	1.760	1.00
242.9	38	133	.0042	1.757	1.00	241	38	134	.0043	1.726	1.00	240	38	133	.0042	1.768	0.99
368.6	60	133	.0039	1.755	0.99	365	59	134	.0038	1.759	1.00	364	59	133	.0038	1.791	1.00
465.2	60	133	.0038	1.757	1.00	463	59	134	.0039	1.743	1.00	461	59	133	.0039	1.795	1.00
715.8	56	134	.0039	1.773	1.00	713	56	135	.0039	1.764	1.00	709	56	131	.0039	1.839	1.00
915.9	55	135	.0038	1.777	1.00	908	54	133	.0040	1.752	1.00	901	54	129	.0040	1.848	1.00

Galvanized Steel.						Galvanized Wrought Iron.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
6.1	50	132	.0040	1.790	1.00	5.8	50	128	.0041	1.825	0.99
11.8	53	129	.0039	1.865	1.00	11.3	53	121	.0042	1.910	0.99
30.4	63	131	.0036	1.937	1.00	29.8	63	120	.0041	1.972	1.00
49.0	71	132	.0036	1.870	1.01	44.4	71	124	.0039	1.952	1.09
84.0	63	133	.0036	1.881	1.02	75.9	64	128	.0037	1.925	1.01
169	37	130	.0039	1.891	1.01	160	37	122	.0041	1.975	1.01
251	38	131	.0039	1.867	1.01	250	38	125	.0041	1.920	1.00
331	54	134	.0035	1.916	1.03	318	54	128	.0037	1.965	1.02
384	59	133	.0037	1.874	1.01	370	59	129	.0037	1.950	1.02
485	59	133	.0037	1.870	1.01	470	59	128	.0037	1.942	1.02
743	56	133	.0036	1.876	1.02	726	56	131	.0035	1.980	1.03
941	54	126	.0041	1.862	0.99	929	54	127	.0038	1.943	1.02

Steel.						Wrought Iron.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
1.4	46	135	.0039	1.785	1.00	3.9	46	129	.0044	1.738	0.98
6.7	53	129	.0041	1.826	0.99	6.9	53	126	.0042	1.823	0.98
12.1	53	118	.0043	2.00	1.00	13.5	54	122	.0042	1.940	1.00
28.9	63	105	.0053	2.000	0.96	30.2	63	115	.0046	1.911	0.97
43.1	71	89	.0072	2.000	0.90	45.2	72	94	.0065	2.000	0.92
68.0	63	71	.0110	1.988	0.83	72.0	63	75	.0099	1.979	0.84
100	50	72	.0106	2.000	0.83	107	50	77	.0093	2.000	0.85
126	36	72	.0107	2.000	0.83	134	36	75	.0097	2.000	0.85
174	37	71	.0111	1.989	0.83	184	37	74	.0101	2.000	0.84
220	54	72	.0107	2.000	0.83	230	54	64	.0132	1.980	0.79
247	59	59	.0156	1.971	0.77	258	60	64	.0132	1.986	0.79
260	68	60	.0151	1.984	0.77	273	68	65	.0128	2.000	0.81
287	66	55	.0176	1.962	0.75	303	66	60	.0151	1.978	0.77
294	59	56	.0172	1.990	0.76	311	60	59	.0151	2.000	0.77
355	37	47	.0238	1.983	0.71	378	36	49	.0218	1.983	0.72
397	56	45	.0255	1.976	0.70	422	58	46	.0242	1.973	0.70
465	53	38	.0350	1.989	0.66	493	53	37	.0364	1.971	0.65

Note: Values of C_W are averages for velocities of 1, 2 and 3 ft. per second and for a water temperature of 59° F. (15° C.)

tions in a widely varying experience, the authors in their calculation took account of: (1) the velocity effects by determining the average value of C_w for the common velocities of 1, 2 and 3 ft. per second; (2) the diameter effects by dealing only with one, essentially uniform size of pipe in each

TABLE 4.— CHANGES IN HYDRAULIC CHARACTERISTICS WITH SERVICE.

$\frac{3}{4}$-in. Pipes.

Temperature: 36° to 77° F.

(Amount of water passed Q' in 1 000 cu. ft.; temperature t in ° F.)

COPPER.						RED BRASS.						ADMIRALTY METAL.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
0.3	53	143	.0075	1.761	1.03	0.1	50	142	.0077	1.770	1.03	0.1	54	150	.0070	1.747	1.05
6.0	61	143	.0073	1.772	1.03	5.9	63	155	.0063	1.773	1.07	5.7	64	145	.0072	1.738	1.04
8.8	71	149	.0066	1.734	1.05	8.8	71	155	.0062	1.720	1.07	8.8	71	155	.0063	1.723	1.07
13.3	62	154	.0063	1.771	1.06	13.0	63	132	.0085	1.744	1.00	12.6	63	132	.0087	1.740	1.00
23.1	49	132	.0089	1.765	1.00	22.0	49	133	.0090	1.747	1.00	21.4	49	132	.0091	1.746	1.00
58.3	39	130	.0097	1.749	0.99	56.7	37	133	.0093	1.747	1.01	56.0	39	132	.0094	1.755	1.00
103	67	129	.0088	1.741	0.99	102	66	134	.0082	1.761	1.01	101	69	131	.0085	1.772	1.00
142	59	130	.0089	1.746	0.99	141	59	133	.0087	1.745	1.00	140	58	130	.0088	1.770	1.00
220	58	130	.0090	1.748	0.99	218	60	133	.0085	1.771	1.00	216	69	131	.0085	1.814	1.00
265	53	130	.0091	1.753	0.99	263	50	132	.0089	1.767	1.00	260	49	128	.0092	1.803	0.99

GALVANIZED STEEL.						GALVANIZED WROUGHT IRON.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
0.1	53	140	.0076	1.781	1.02	0	54	113	.0109	1.856	0.95
5.6	63	110	.0104	2.000	0.95	4.6	63	88	.0156	2.000	0.88
9.1	71	135	.0073	1.898	1.01	7.4	71	105	.0117	1.917	0.93
13.3	63	126	.0087	1.871	0.99	11.1	62	107	.0110	1.926	0.94
22.6	48	124	.0095	1.825	0.98	19.4	49	113	.0111	1.887	0.94
57.9	39	120	.0100	1.868	0.97	51.7	40	113	.0113	1.893	0.94
84.7	55	124	.0091	1.846	0.98	76.2	55	112	.0109	1.880	0.94
104	69	125	.0087	1.870	0.98	93.2	69	114	.0102	1.960	0.95
143	59	125	.0091	1.823	0.98	128	59	111	.0109	1.896	0.94
220	61	124	.0090	1.875	0.98	198	61	112	.0105	1.936	0.95
262	50	94	.0139	1.989	0.90	237	50	102	.0129	1.918	0.91

STEEL.						WROUGHT IRON.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
0.1	63	129	.0090	1.766	0.99	0.1	54	131	.0088	1.755	1.00
5.3	61	119	.0094	1.925	0.97	5.6	63	136	.0076	1.858	1.01
8.2	72	118	.0097	1.856	0.96	8.9	72	138	.0071	1.928	1.03
12.3	62	111	.0105	1.926	0.95	13.2	63	93	.0150	1.924	0.88
20.0	49	80	.0190	1.968	0.84	20.4	49	88	.0163	1.947	0.87
42.8	40	66	.0270	2.000	0.79	44.0	40	68	.0258	2.000	0.79
57.6	55	59	.0330	1.988	0.75	59.0	54	61	.0319	1.985	0.76
66.8	67	56	.0364	1.971	0.74	68.3	68	59	.0337	1.930	0.75
71.0	69	55	.0377	1.945	0.73	72.6	69	57	.0360	1.921	0.74
82.6	66	55	.0376	1.940	0.73	83.7	66	52	.0429	1.933	0.71
85.2	60	54	.0376	2.000	0.74	86.2	59	51	.0439	1.941	0.71
106	40	34	.0910	1.980	0.62	106	38	36	.0880	1.924	0.62
113	62	30	.1160	1.959	0.58	113	61	30	.1190	1.945	0.58
124	54	24	.1720	1.965	0.54	124	51	28	.1360	1.918	0.57

NOTE: Values of C_W are averages for velocities of 1, 2 and 3 ft. per second and for a water temperature of 59° F. (15° C.)

battery; (3) the temperature effects by reducing to a common basis of 59° F. (15° C.)* all values of s used in the computations of C_W.

Values of C_W calculated with the aid of the Hazen-Williams slide rule, with the restrictions as to velocity and temperature noted above, were determined for the entire series of tests and are recorded, together with the values of Q', the amount of water delivered by the pipes previous to each

*The effect of temperature upon the value of s was shown by one of us (C. Y. H.) to take the following form:

$\frac{s_2}{s_1} = \left(\frac{\nu_2}{\nu_1}\right)^{2-n}$; where ν is the kinematic viscosity of the water $\left(\nu = \frac{\mu}{\rho}\right.$; where μ is the absolute viscosity and $\left.\rho$ is the density$\right)$ and n is the exponent of v in the general equation: $s = Mv^n$. It was further shown that for most practical purposes the value of ν, ordinarily obtainable only from special tables, may be approximated by the equation: $\nu = \frac{0.003686}{t^{1.3}+100}$ in which t equals temperature in ° F. Since in the Hazen-Williams formula n equals 1.85, $\frac{s_2}{s_1} = \left(\frac{\nu_2}{\nu_1}\right)^{0.15} = \left(\frac{t_1^{1.3}+100}{t_2^{1.3}+100}\right)^{0.15}$ approximately.

TABLE 5.— CHANGES IN HYDRAULIC CHARACTERISTICS WITH SERVICE.

¾-in. Pipes.

Temperature 140° F. ±

(Amount of water passed Q' in 1 000 cu. ft.; temperature t in ° F.)

COPPER.						RED BRASS.						ADMIRALTY METAL.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
0	74	128	.0089	1.688	0.99	0	56	132	.0089	1.738	1.00	0	47	133	.0093	1.730	1.00
10	55	131	.0090	1.734	1.00	6.3	41	132	.0094	1.748	1.00	6.8	60	133	.0086	1.746	1.00
11.2	56	131	.0089	1.730	1.00	14.2	39	132	.0094	1.750	1.00	10.0	71	132	.0084	1.730	1.00
13.5	56	131	.0089	1.721	1.00	.....	..	...	.....	.....	....	12.5	55	133	.0089	1.724	1.00
17.4	66	130	.0087	1.742	1.00	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....
38.8	69	131	.0084	1.741	1.00	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....
39.7	67	132	.0084	1.752	1.00	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....
44.6	64	131	.0085	1.742	1.00	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....
53.2	59	131	.0087	1.754	1.00	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....
77.4	38	131	.0096	1.742	0.99	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....
93.7	48	130	.0094	1.733	1.00	.....	..	...	.....	.....	....	.....	..	...	.....	.....	....

GALVANIZED STEEL.						GALVANIZED WROUGHT IRON.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
0	56	117	.0121	1.986	0.92	0	72	109	.0125	1.905	0.91
2.7	60	96	.0127	1.979	0.91	0.2	66	90	.0150	2.000	0.88
2.8	71	98	.0128	2.000	0.91	3.8	62	94	.0140	1.998	0.90
5.7	71	95	.0136	1.988	0.90	10.3	62	93	.0142	1.980	0.89
8.1	56	91	.0146	1.982	0.89	21.7	40	82	.0177	2.000	0.86
.....	..	...	.....	.....	....	31	39	76	.0203	2.000	0.83

STEEL.						WROUGHT IRON.					
Q'	t	C_W	M	n	d_e/d	Q'	t	C_W	M	n	d_e/d
0	37	124	.0103	1.886	0.96	0	74	122	.0099	1.772	0.96
0.6	42	45	.0546	1.975	0.68	0.7	59	21	.2380	1.943	0.50
1.1	39	34	.0984	1.921	0.61	0.9	64	16	.3940	1.931	0.45
1.5	39	26	.1490	2.000	0.56	1.0	65	13	.5750	1.935	0.42
2.1	39	19	.2760	1.966	0.49	1.5	67	11	.7950	1.940	0.39
2.4	42	16	.3690	2.000	0.47	2.9	77	6	2.750	2.000	0.31
3.0	43	10	.8650	1.985	0.39	.....	..	...	.....	.....	....
3.05	45	10	.8950	2.000	0.39	.....	..	...	.....	.....	....
3.1	47	9	1.140	1.975	0.37	.....	..	...	.....	.....	....

NOTE: Values of C_W are averages for velocities of 1, 2 and 3 ft. per second and for a water temperature of 59° F. (15° C.)

test, in Tables 3, 4 and 5 for the three batteries of pipes. The data are also shown graphically in Figures 3, 4 and 5.

The curves show in a striking manner the effect of service, as measured by quantity of water passed, upon the hydraulic characteristics of the different pipe materials when exposed to Cambridge water under the test conditions. In general, the progressive changes are the same for all three groups, varying only in magnitude. An examination of the results will show that the copper, red-brass and admiralty-metal pipes suffered little or no reduction in carrying capacity, the galvanized steel and galvanized wrought-iron pipes showed some reduction, whereas the capacities of the steel and wrought-iron pipes were decreased to a very marked extent.

To give a more direct comparison between the various materials, the relative carrying capacities have been calculated in terms of the relative carrying capacity of copper pipe and are recorded in Table 6 for certain values of Q'. As previously stated, the relative carrying capacity of one pipe in terms of that of another of the same diameter is given by the ratio of their coefficients C_W. The values given in Table 6 were obtained by

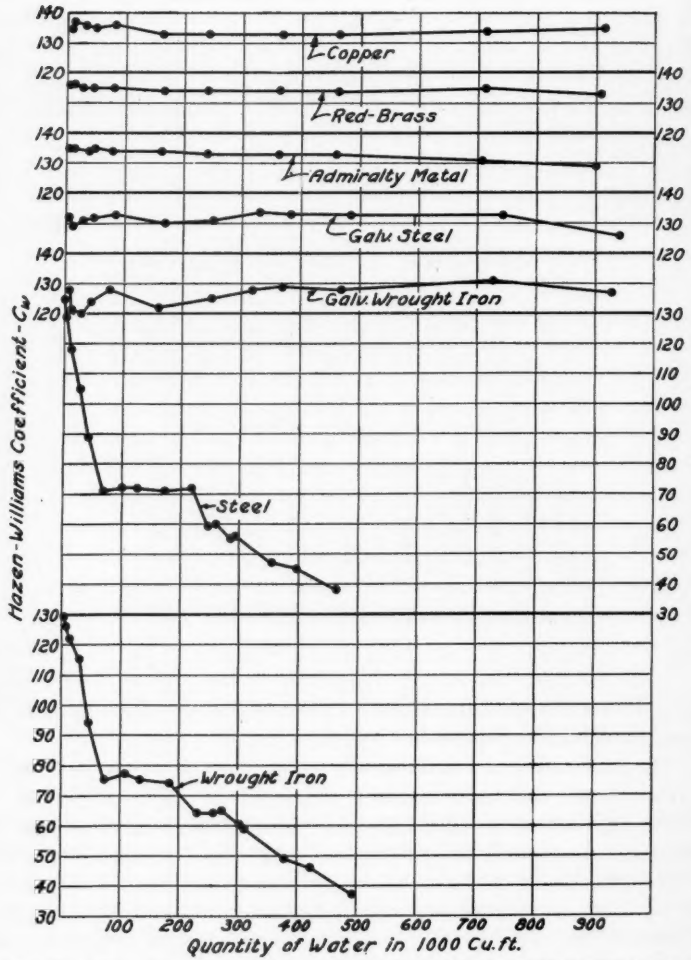


FIG. 3.— HYDRAULIC SERVICE CHARACTERISTICS OF 1½-IN. COLD-WATER PIPES AS MEASURED BY THE HAZEN-WILLIAMS COEFFICIENT C_w.

Service measured by the total quantity of water delivered by the pipes from the beginning of the test.

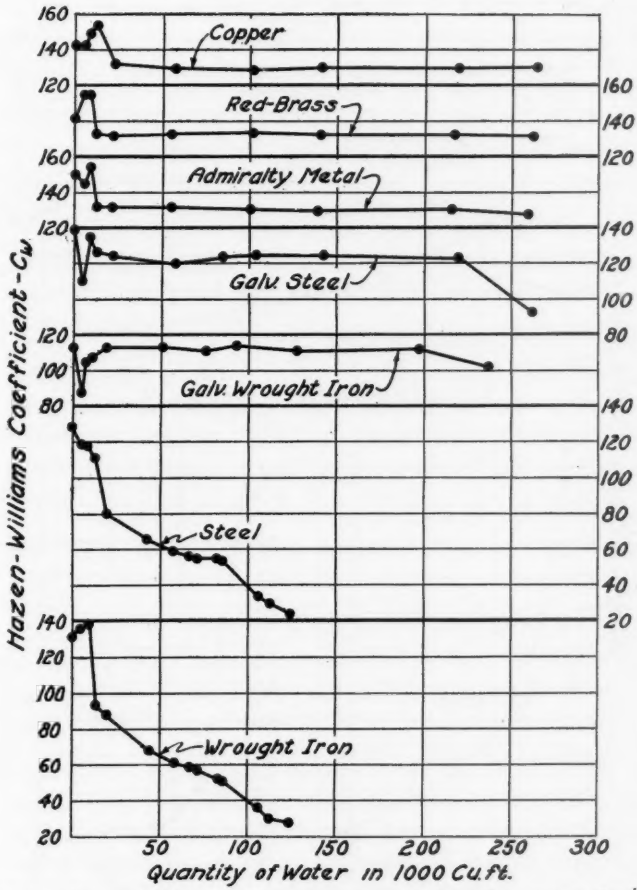


FIG. 4.— HYDRAULIC SERVICE CHARACTERISTICS OF ¾-IN. COLD-WATER PIPES AS MEASURED BY THE HAZEN-WILLIAMS COEFFICIENT C_W.

Service measured by the total quantity of water delivered by the pipes from the beginning of the test.

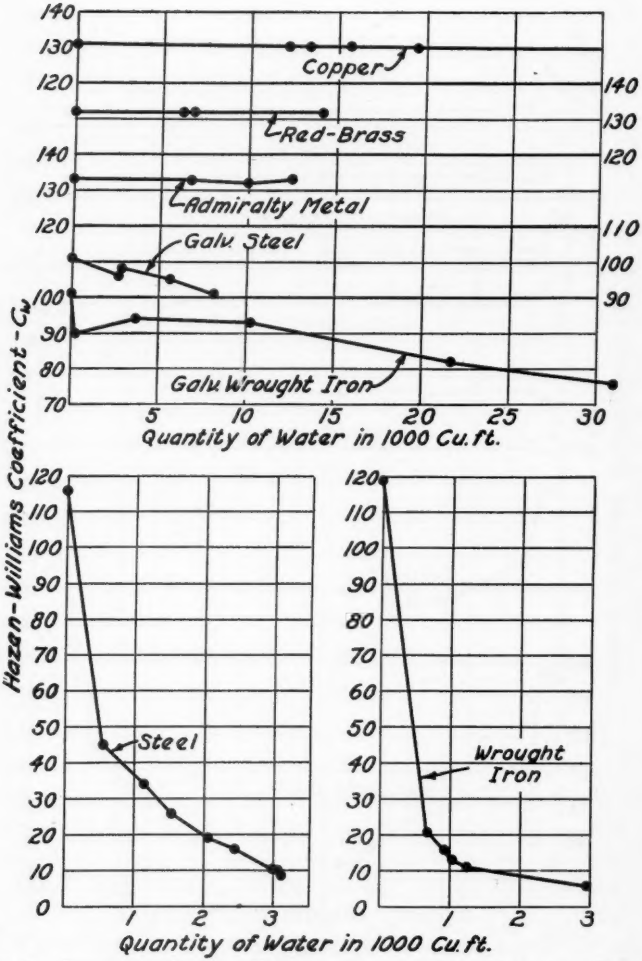


FIG. 5.— HYDRAULIC SERVICE CHARACTERISTICS OF $\frac{3}{4}$-IN. HOT-WATER PIPES AS MEASURED BY THE HAZEN-WILLIAMS COEFFICIENT C_W.

Service measured by the total quantity of water delivered by the pipes from the beginning of the test.

applying this principle, the ratios being calculated from values of C_w taken directly from the curves of Figures 3, 4 and 5 and being expressed as percentages.

Battery I; 1½-in. Cold-water Pipes. The data for Battery I (1½-in. cold-water pipes) show that the red-brass and admiralty-metal pipes behaved quite similarly to the copper pipe, although, as shown in Figure 3 and Table 3, there appears to be a significant decreasing trend in the relative capacity of the admiralty-metal pipe, the value of C_w falling from 135 to 129 or 4.5 per cent. For practical purposes one may say that during a service period equivalent to the delivery of almost one million cubic feet of water, the pipes showed no appreciable hydraulic deterioration. Use of a value of 130 for C_w appears conservative.

The galvanized-steel and wrought-iron pipes had initial capacities slightly lower than copper. There was an improvement in their hydraulic characteristics, however, with use, and after delivery of almost one million cubic feet of water they had experienced only a slight reduction from their original capacities ($C_w = 127$).

The data for the steel and iron pipes, on the other hand, show that marked changes took place. Starting with relative capacities significantly lower than the relative capacity of the copper pipe, they suffered rapid deterioration with service. Capacities only slightly over one-half the capacity of the copper pipe obtained after discharging 200 000 cu. ft. of water ($C_w = 72$), and a further reduction to 27 per cent. relative to copper was observed after the delivery of 500 000 cu. ft. ($C_w = 35$). After passing the latter quantity of water, they were equivalent only to a one-inch copper pipe.

Battery II; ¾-in. Cold-water Pipes. Turning to the data in Table 4 and Figure 4 for Battery II (¾-in. cold-water pipes), one again observes that the red-brass and admiralty-metal pipes possessed hydraulic service properties about equal to those of the copper pipe during a period of service represented by the delivery of a quarter million cubic feet of water ($C_w = 130$).

The galvanized pipes too, showed little reduction in capacity until 200 000 cu. ft. of water had passed through them ($C_w = 112$ and 125). There was a sudden drop in capacity at this point, however, and after the delivery of 250 000 cu. ft. of water their carrying capacities were only about 80 per cent. of the copper pipe rating ($C_w = 104$). The extremely low initial capacity of the galvanized wrought-iron pipe is somewhat misleading. It was probably caused by some local obstruction that was washed away at a later period.

The steel and wrought-iron pipes of this group suffered rapid and extensive reduction in carrying capacity. Starting with capacities relative to copper pipe of 90 to 92 per cent., they were able to deliver only one-half as much water as the copper pipe after a service period gaged by the passage of 50 000 cu. ft. of water ($C_w = 65$). There was a continuous reduction with service. After the delivery of 125 000 cu. ft. of water, capacities of about

TABLE 6.— RELATIVE CARRYING CAPACITY IN TERMS OF THE CAPACITY OF COPPER PIPE AFTER DELIVERY OF STATED QUANTITIES OF WATER.

1½-in. Pipes.— Temperature: 36° to 77° F.

	QUANTITY OF WATER DELIVERED IN 1 000 CU. FT.									
	0	100	200	300	400	500	600	700	800	900
Copper	100	100	100	100	100	100	100	100	100	100
Red Brass	101	100	101	101	101	101	101	101	100	98.6
Admiralty Metal	100	99.3	100	100	100	100	99.3	97.8	97.0	95.5
Galvanized Steel	97.7	97.7	97.7	99.2	100	100	100	99.3	97.8	94.1
Galvanized Wrought Iron	94.8	93.3	92.4	95.5	96.2	97.0	97.0	97.0	96.3	94.8
Steel	92.5	53.3	53.4	41.3	34.8	27.0	.....	.....	.....	.....
Wrought Iron	95.6	56.3	52.6	45.9	35.3	27.0	.....	.....	.....	.....

¾-in. Pipes.— Temperature: 36° to 77° F.

	QUANTITY OF WATER DELIVERED IN 1 000 CU. FT.										
	0	25	50	75	100	125	150	175	200	225	250
Copper	100	100	100	100	100	100	100	100	100	100	100
Red Brass	100	100	102	103	104	102	102	102	102	102	102
Admiralty Metal	106	100	102	102	102	101	100	100	101	100	99
Galvanized Steel	98.6	93.1	93.1	94.6	96.8	96.8	96.2	95.5	95.5	92.4	78.5
Galvanized Wrought Iron	79.6	85.6	86.8	86.0	87.6	86.0	85.4	85.4	85.4	80.7	.....
Steel	90.8	58.3	48.4	42.6	31.0	18.6	.....	.....	.....	.....	.....
Wrought Iron	92.3	63.6	50.0	42.7	31.0	21.7	.....	.....	.....	.....	.....

¾-in. Pipes.— Temperature: 140° F. ±

	QUANTITY OF WATER DELIVERED IN 1 000 CU. FT.												
	0	.5	1	1.5	2.0	2.5	3	5	10	15	20	25	30
Copper	100	100	100	100	100	100	100	100	100	100	100	100	100
Red Brass	103	102	102	102	102	102	102	102	102	102	.....	.....	.....
Admiralty Metal	102	102	102	102	102	102	102	102	102	.....	.....	.....	.....
Galvanized Steel	90.0	77.0	76.1	75.3	74.6	73.8	75.3	73.8	.....	.....	.....	.....	.....
Galvanized Wrought Iron	84.0	69.2	69.2	70	70.8	70.8	71.4	72.3	71.5	67.7	64.6	61.5	58.5
Steel	95.0	40.8	28.5	20.8	15.4	11.5	7.7	.....	.....	.....	.....	.....	.....
Wrought Iron	94.0	35.4	10.8	7.7	6.9	5.4	4.6	.....	.....	.....	.....	.....	.....

20 per cent. relative to copper obtained ($C_w = 25$). In other words, the steel and wrought-iron pipes were equivalent only to a $\frac{3}{8}$-in. copper pipe after this length of service.

Battery III; $\frac{3}{4}$-in. Hot-water Pipes. Because of intensified physical and chemical activity due to the higher water-temperature, marked changes in the pipes of Battery III ($\frac{3}{4}$-in. hot-water pipes) were observed (see Fig. 5). Unfortunately, the red-brass and admiralty-metal pipes were in service for only short periods (15 000 cu. ft.), and although they showed no changes in carrying capacity during this time, definite comparison cannot be made with the resistive qualities of copper pipe, which delivered a total of 93 000 cu. ft. of water during the period of investigation.

The galvanized pipes were affected to an appreciable extent. With initial values relative to copper of 84 and 90 per cent., the capacities were reduced to 73 per cent. after the delivery of 5 000 cu. ft. of water ($C_w = 95$*), and, in the case of the galvanized wrought-iron pipe, there was a further reduction to 58 per cent. at the end of its service period of 30 000 cu. ft. of water ($C_w = 76$); it was then equivalent only to a $\frac{1}{2}$-in. copper pipe. The results show clearly that in hot-water systems the protective coating provided by the galvanizing process does not stand up so well as in cold-water systems.

The steel and wrought-iron pipes in this group manifested very rapid changes in their hydraulic characteristics. Their initial capacities were fairly high, but after delivering 500 cu. ft. of water, it will be observed that they were capable of delivering less than half as much water as the copper pipe in this battery ($C_w = 50$). After a service period of 3 000 cu. ft. they were almost completely clogged. They would then deliver no more water than a $\frac{1}{8}$-in. copper pipe. The wrought-iron pipe apparently suffered more rapid deterioration during the early stages than did the steel pipe, but at the end of the exposure there was no choice between these two materials.

Relative Effect of Water Temperature and Pipe Diameter. Examination of the results shown in Table 6 gives some idea of the relative effect of water temperature and pipe diameter upon the hydraulic service characteristics of the seven pipe materials as measured by C_w. The materials apparently fall into three general classes: (1) high-copper pipes, including copper, red-brass and admiralty-metal pipes; (2) galvanized-iron pipes, including galvanized wrought iron and galvanized steel; (3) iron pipes, including wrought iron and steel. As shown later, the materials may also be classified in this manner on the basis of the physical appearance of the pipes after protracted service.

The high-copper pipes suffered no significant hydraulic change with service, and no noticeable effects were associated with the differences in pipe diameter and water temperature. The galvanized-iron pipes showed deterioration with service, which was greater for the high than for the low temperature; but there was no marked difference between the flow char-

*All values of C_w are corrected to a water temperature of 59° F.

acteristics of the 1½-in. pipes and ¾-in. pipes in the two cold-water batteries. The iron pipes suffered the greatest change, and the data show that the service characteristics of these pipes varied both with pipe diameter and water temperature. After the delivery of 125 000 cu. ft. of water, the ¾-in. cold-water pipes had capacities relative to copper of about 20 per cent. as compared with 55 per cent. for the 1½-in. pipes delivering water at the same temperature. The effect of temperature is even more pronounced. At the end of a service period of 3 000 cu. ft. of water, the hot-water pipes had capacities relative to copper of 5 and 7 per cent. whereas the capacities of the ¾-in. cold-water pipes had been reduced to only 88 per cent.

Limitations of Results. The data and curves presented for changes in C_w give the hydraulic histories in terms of C_w of pipes of representative materials under conditions of service imposed by the investigation. Water of a definite chemical composition was used, and results were obtained for two pipe diameters and two water temperatures. The velocity and time of flow through the pipes were kept constant. The data are restricted to the conditions of test; consequently the values of the coefficient, C_w, are restricted in their application. Great care should be exercised in the use of these coefficients in the design of systems in which different conditions may obtain. The tables of coefficients are further limited by the fact that the service period used in this investigation is in terms of quantities of water delivered by the pipes. Difficulty may be experienced in translating service from "amount of water delivered" to "time." In house plumbing-systems, furthermore, the velocity of flow fluctuates and at times becomes zero. During this study, on the other hand, the flow was kept constant at one foot a second.

Service Characteristics as Measured by n and d_e/d.

As stated in our theoretical discussion of service characteristics, the progressive changes in the relative carrying capacity of pipes may be thought of as being produced by two factors: (1) the change in surface conditions of pipes as measured by n, and (2) the change in pipe diameter as measured by d_e/d. It was also indicated that the changes, as measured by these factors appear to occur in two stages: the first being characterized by the values of n increasing up to a limiting value of 2.00; the second by the values of d_e/d decreasing from unity to a limiting value of zero in the case of complete clogging.

Values of n and d_e/d have, therefore, been calculated for the entire series of tests and are tabulated together with values of C_w, Q' and other essential data in Tables 3, 4 and 5. Progressive changes of n and d_e/d with service are shown graphically for the series of pipes in Figures 6, 7 and 8. To simplify presentation, the pipes were grouped, according to their resistive qualities, into three classes: (1) high-copper pipes, (2) galvanized-iron pipes and (3) iron pipes.

High-copper Pipes. Examination of the data for the pipes of the high-

copper class indicates that in no case, apparently, did these pipes enter the second stage of reduction in carrying capacity, *i.e.*, the ratio, d_e/d, did not depart from unity (see Figure 6). There was an increase in the value of n, however, which, although comparatively slight, was significant. The rate of change in n with service was the same for copper and red brass, but a more rapid change was observed in the admiralty-metal pipe. Thus, during the entire service period of the 1½-in. pipes, the value of n increased from 1.75 to 1.85 for the admiralty metal, whereas the increase for the copper and red-brass pipes was only from 1.74 to 1.77. The physical appearance of the

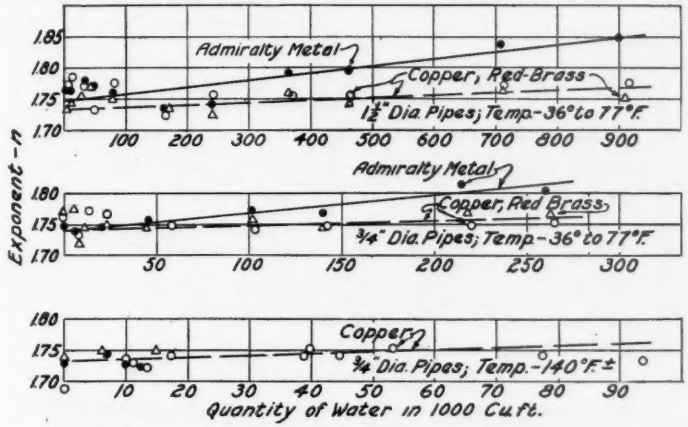


FIG. 6.— HYDRAULIC SERVICE CHARACTERISTICS OF HIGH-COPPER PIPES AS MEASURED BY THE EXPONENT n OF THE VELOCITY v.

There was no significant change in effective diameter d_e and the ratio of effective to original diameter remained essentially 1.00. Service measured by the total quantity of water delivered by the pipes from the beginning of the test.

admiralty-metal pipe (see Figures 9, 10 and 11) also indicates that it was subjected to greater changes than the copper and red-brass pipes.

Since the general trend of change in n with service was linear in each case, the slopes of the lines in Figure 6 constitute a measure of the changing service characteristics of these pipes. Slopes, calculated on the basis of percentage change in n associated with the delivery of unit quantities of 100 000 cu. ft. of water are as follows:

	1½-in. Pipe. Temperature: 36° to 77° F.	¾-in. Pipe. Temperature: 36° to 77° F.	¾-in. Pipe. Temperature: 140° F.±
Copper and Red Brass	0.3	0.8	3.3
Admiralty Metal	1.1	2.8	...

These results indicate a greater change in the admiralty-metal than in the copper and red-brass pipes. They show also the effect of pipe di-

ameter and water temperature upon the rate of change in carrying capacity with service. This effect, it will be remembered, could not be measured by the less sensitive measure of service characteristics, C_w.

Changes in the high-copper pipes were so slight as to be of little practical importance. The change in n with service can therefore be ignored in practice and an average value used. The average of the values observed

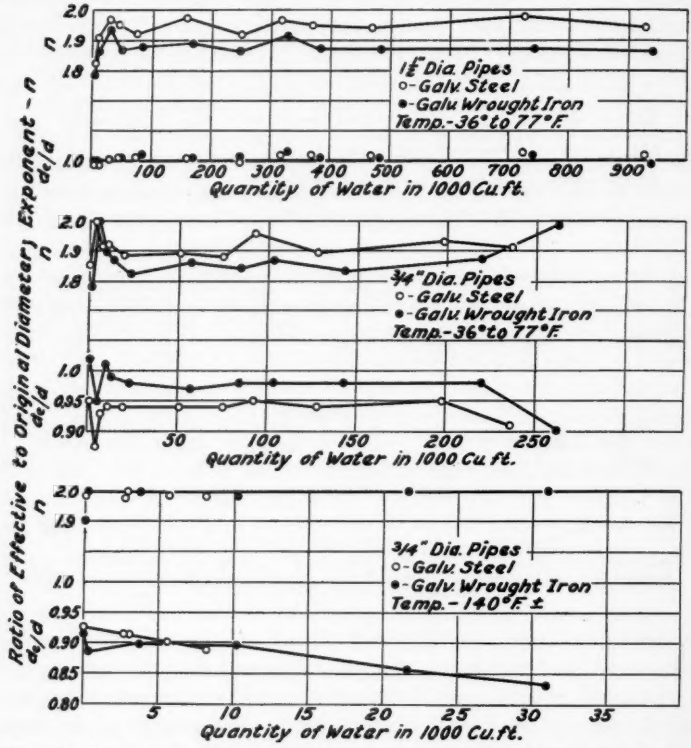


FIG. 7.— HYDRAULIC SERVICE CHARACTERISTICS OF GALVANIZED-IRON PIPES AS MEASURED BY THE EXPONENT n OF THE VELOCITY v AND BY THE RATIO OF THE EFFECTIVE DIAMETER d_e TO THE ORIGINAL DIAMETER d.

Service measured by the total quantity of water delivered by the pipes from the beginning of the test.

during this investigation was 1.754, and the authors believe that this average can be employed with safety in the calculation of frictional losses in high-copper pipes.

Galvanized-iron Pipes. Hydraulic changes in the galvanized-iron pipes are illustrated in Figure 7. The 1½-in. pipes were apparently subjected to first-stage changes only, the ratio d_e/d remaining unity throughout the entire period of service. A marked increase in n occurred at the outset, but little change was noted thereafter. The galvanized-steel pipe had a higher

value of n than the galvanized wrought-iron pipe, 1.95 as compared with 1.88, indicating superior hydraulic characteristics on the part of the latter.

The $\frac{3}{4}$-in. cold-water pipes of this class were more seriously affected by service, apparently being subjected to second- as well as first-stage changes in carrying capacity. The value of n was again higher for the galvanized-steel pipe than for the galvanized wrought-iron pipe, although a

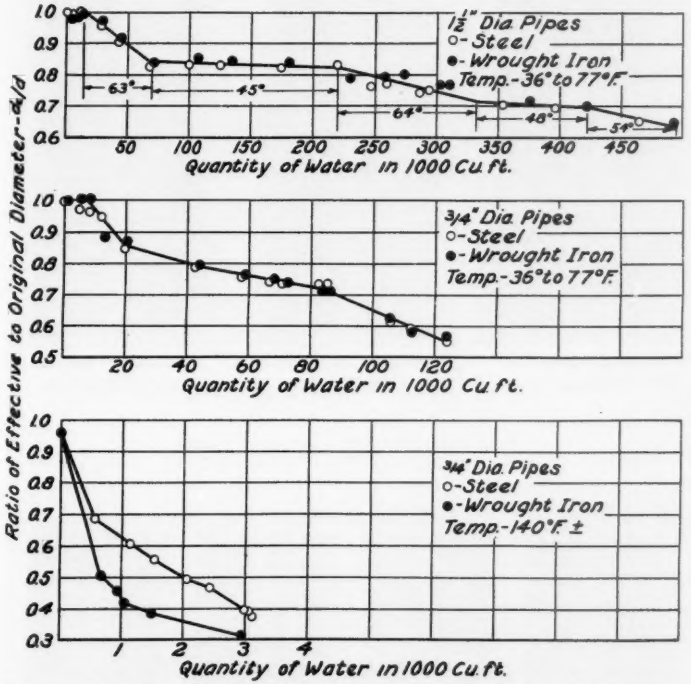


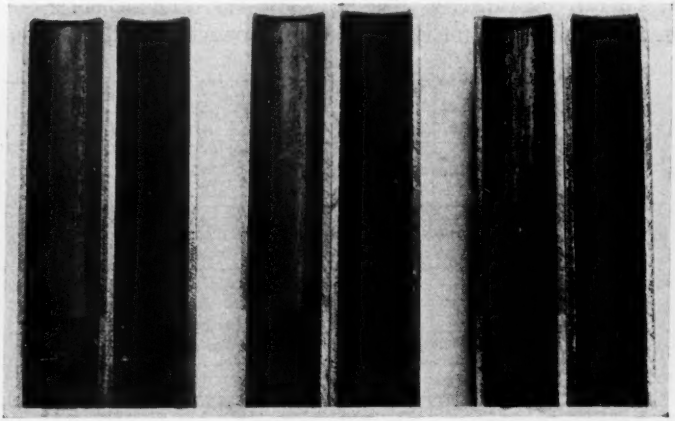
FIG. 8.— HYDRAULIC SERVICE CHARACTERISTICS OF IRON PIPES AS MEASURED BY THE RATIO OF THE EFFECTIVE DIAMETER d_e TO THE ORIGINAL DIAMETER d.
The exponent n of the velocity v took a limiting value of 2.00 practically at the start of the tests. Service measured by the total quantity of water delivered by the pipes from the beginning of the test.

sudden increase at the end of the service period gave the latter a higher value. The ratio, d_e/d, which was irregular at first, assumed approximately constant values of 0.975 and 0.950 for the galvanized wrought-iron pipe and galvanized-steel pipe respectively. After the delivery of 200 000 cu. ft. of water, however, there was a sudden drop in the ratio, resulting in a value of 0.9 for both pipes. This reduction corresponds to the increase in n observed at the end of the service period of the galvanized wrought-iron pipe.

The two galvanized-iron pipes in the hot-water group were apparently subjected to second-stage changes almost immediately after being placed

Total Quantity of Water Delivered (cu. ft.)

916 000 *908 000* *901 000*

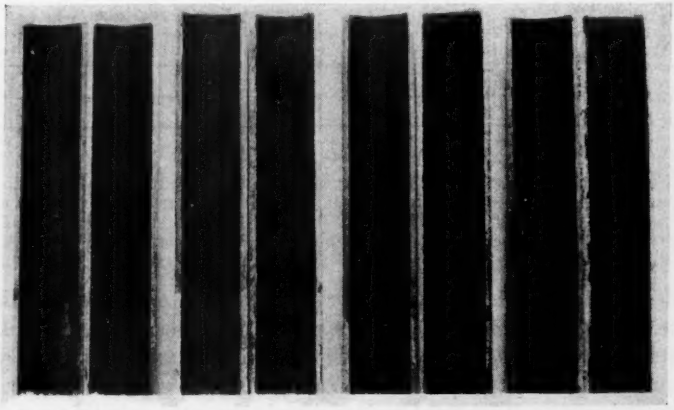


Cleaned. Uncleaned. *Cleaned. Uncleaned.* *Cleaned. Uncleaned.*

Copper *Red Brass* *Admiralty Metal*

Total Quantity of Water Delivered (cu. ft.)

941 000 *929 000* *465 000* *493 000*



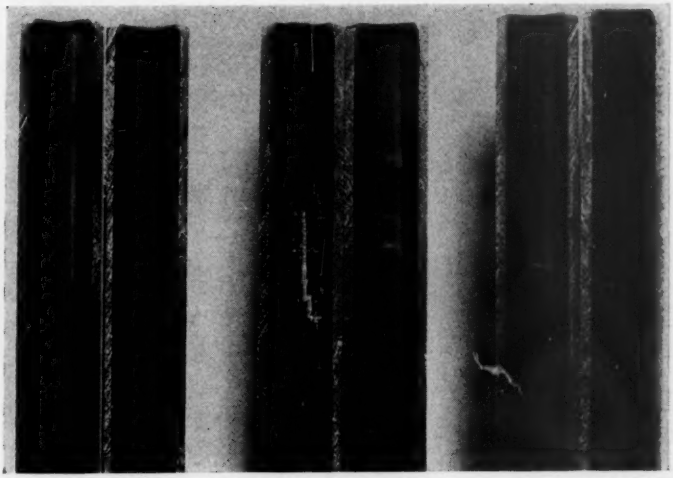
Cleaned. Uncleaned. *Cleaned. Uncleaned.* *Cleaned. Uncleaned.* *Cleaned. Uncleaned.*

Gal. Steel *Galv. Wrought Iron* *Steel* *Wrought Iron*

FIG. 9.— CONDITION OF 1½-IN. COLD-WATER PIPES AT END OF INVESTIGATION.
Water temperature: 36° to 77° F.

Total Quantity of Water Delivered (cu. ft.)

265 000 *263 000* *260 000*

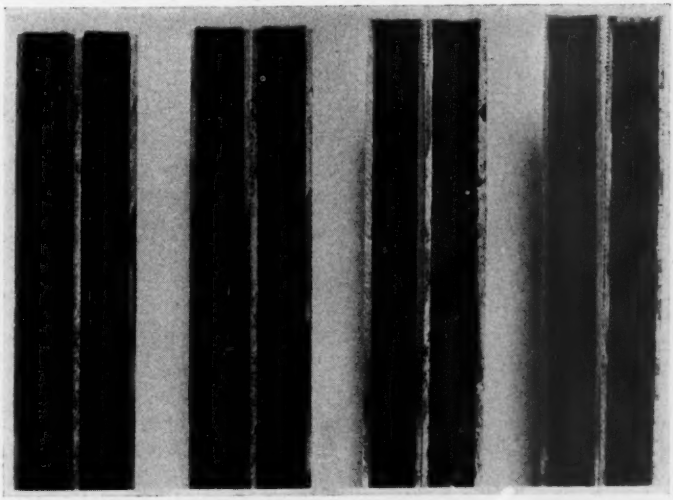


Cleaned. Uncleaned. *Uncleaned. Cleaned.* *Cleaned. Uncleaned.*

Copper *Red Brass* *Admiralty Metal*

Total Quantity of Water Delivered (cu. ft.)

262 000 *237 000* *124 000* *124 000*



Cleaned. Uncleaned. *Cleaned. Uncleaned.* *Cleaned. Uncleaned.* *Cleaned. Uncleaned.*

Galv. Steel *Galv. Wrought Iron* *Steel* *Wrought Iron*

FIG. 10.— CONDITION OF $\frac{3}{4}$-IN. COLD-WATER PIPES AT END OF INVESTIGATION.
Water temperature: 36° to 77° F.

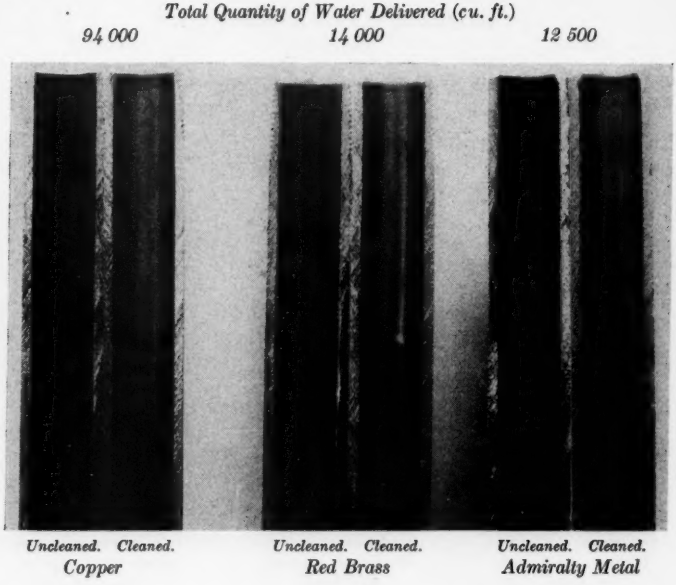


FIG. 11.— CONDITION OF ¾-IN. HOT-WATER PIPES AT END OF INVESTIGATION.
Water temperature: 140° F. ±

in service. The value of n became 2.00, and the reduction in diameter was rapid. For the galvanized wrought-iron pipe, the ratio, d_e/d, which was 0.93 at the beginning, was reduced to 0.83 after the delivery of 30 000 cu. ft. of water. Changes in the ratio for the galvanized-steel pipe were of the same order of magnitude. The effect of water temperature upon the rate of change in capacity with service is well illustrated in the hydraulic histories of these pipes.

The superiority of galvanized-iron pipes as compared with uncoated iron pipes disappears when the protective coating is destroyed. An examination of the physical appearance of the galvanized pipes tested in this study (see Figures 9, 10 and 11) indicates that the coating had deteriorated with service. The damage was not great in the case of the $1\frac{1}{2}$-in. cold-water pipes, but the coating of the $\frac{3}{4}$-in. cold-water pipes was almost gone. In the case of the $\frac{3}{4}$-in. hot-water pipes, it had disappeared altogether. Results of the hydraulic tests vary in the same order. There was practically no change in the $1\frac{1}{2}$-in. pipes. The sudden increase in n and decrease in d_e/d at the end of the service period of the $\frac{3}{4}$-in. cold-water pipes indicates a rapid destruction of the protective coating at that time. The rapid decrease in d_e/d for the $\frac{3}{4}$-in. hot-water pipes suggests that the destruction of the galvanizing took place very quickly after these pipes were put in service.

Iron Pipes. Turning now to the curves for the uncoated steel and wrought-iron pipes (Figure 8), it will be observed that these pipes apparently suffered second-stage changes almost from the beginning of the tests. The changes in n are not shown in Figure 8, but an examination of the tabulated values shows that values of 2.00 or slightly less obtained from the start. Average values of n throughout the period of investigation were as follows: For the $1\frac{1}{2}$-in. cold-water pipes, 1.989; for the $\frac{3}{4}$-in. cold-water pipes, 1.954; for the $\frac{3}{4}$-in. hot-water pipes, 1.961. There was a constant reduction in diameter in the case of each test pipe, the change being greater for the $\frac{3}{4}$-in. pipes than for the $1\frac{1}{2}$-in. pipes and much more rapid in the hot-water pipes than in those carrying cold water.

The effect of water temperature upon the service characteristics of water pipes is also illustrated in a striking manner in the curve for the $1\frac{1}{2}$-in. pipes (Figure 8). It will be observed that the progressive changes are characterized by six definite steps. The first step, which constituted a period of no change in diameter, continued for a period of service of 12 000 cu. ft. of water. This was followed by a shart decline in the curve. After the delivery of 70 000 cu. ft. of water, however, the curve became almost flat. This step was followed by another of higher slope, after which a second flat section occurred, being succeeded by a third period of rapid changes. These alternating sections of the curve, having different slopes, correspond to seasonal changes in water temperature. The sections having greater slopes are for summer periods, when the water temperature was high, whereas the flat portions of the curve correspond to the winter periods. Average water temperatures during these alternating periods are indicated on the curve.

Discussion and Formulation of Hydraulic Characteristics as Measured by n and d_e/d. The use of n and d_e/d as measures of roughness provides a sensitive index for the hydraulic characteristics of water pipes and for the progressive changes in carrying capacity that take place with service. Comparison of the service characteristics of different pipe materials on the basis of changes in these indices brings out characteristics not always shown when the Hazen-Williams coefficient C_w is used as the basis of comparison.

This is well illustrated by the results for the high-copper pipes. The increase in n indicates that these pipes were subject to significant changes in carrying capacity. The value of their Hazen-Williams coefficient, C_w, on the other hand, remained practically constant throughout the entire period of investigation. Another advantage in the use of n and d_e/d lies in the fact that the calculated pipe losses are more exact and are not dependent upon other factors such as water temperature and velocity. For practical purposes, the authors suggest the use of the following formulas in the calculation of pipe losses:

For *copper*, *red-brass* and *admiralty-metal* pipes, 1½-in. and ¾-in. in diameter, a constant value of 1.754 may be assumed for n throughout a service period of respectively 1 000 000 and 300 000 cubic feet of water at normal temperatures. No reduction in diameter will generally take place during this period, so that the original diameter controls. The resulting mathematical relationship takes the form:

$$s = Mv^{1.754}$$

$$\text{where } M = 0.00495 \left(\frac{\rho}{\mu}\right)^{-0.246} d^{-1.246}$$

For a normal water temperature of 59° F.* (15° C.), therefore, the slope S in feet per 1 000 feet is given by:

$$S = 0.307\, d^{-1.246}\, v^{1.754},$$

whence the discharge G in g.p.m. for any small diameter D in inches may be calculated by:

$$G = 0.822\, D^{2.71}\, S^{0.57}$$

For hot water of 140° F.† (60° C.), the relations become:

$$S = 0.247\, d^{-1.246}\, v^{1.754}; \text{ and}$$

$$G = 0.930\, D^{2.71}\, S^{0.57}$$

For comparison we may write the Hazen-Williams equation in corresponding form as follows:

$$G = 0.00675\, C_w\, D^{2.63}\, S^{0.54}$$

For normal water temperatures and hot water respectively the values of C_w that give the same discharge as the suggested formulas for a diameter of 1 in. and a slope of 10 ft. per 1 000 ft. are 130 and 147.

Galvanized-steel and *wrought-iron* pipes, 1½-in. and ¾-in. in diameter, *delivering cold water* may be assumed to remain unchanged during service

* $\frac{\mu}{\rho} = 0.00001229$.

† $\frac{\mu}{\rho} = 0.000005132$.

periods equivalent to the delivery of 900 000 and 200 000 cu. ft. of water respectively. An average value of 1.880 may be assigned to n, giving the following equation:

$$s = Mv^{1.88}$$

$$\text{where } M = 0.0016 \left(\frac{\rho}{\mu}\right)^{-0.12} d^{-1.12}$$

For a normal water temperature of 59° F., the relation becomes:

$$S = 0.52\, d^{-1.12}\, v^{1.88} \text{ and}$$

$$G = 0.780\, D^{2.60}\, S^{0.53}$$

In the case of a 1-in. pipe and a slope of 10 ft. per 1 000 ft. a value of $C_w = 113$ in the Hazen-Williams equation gives the same discharge as this formula.

In the case of the $\frac{3}{4}$-in. pipes, there was a sudden change in n and d_e/d after the delivery of 200 000 cu. ft. of water, so that this expression would not hold during further service.

The *galvanized-iron* pipes in the *hot-water* group were subjected to second-stage changes, and n was increased to 2.00 at the very beginning. The equation for these pipes, therefore, takes the form:

$$s' = Mv^2_e$$

where $M = 0.00056\, d_e^{-1}$, the factor $\left(\frac{\rho}{\mu}\right)^{-0}$ becoming unity, and d_e being the effective diameter for the desired value of Q'.

In this equation, s' is the hydraulic slope obtaining after a service period equivalent to Q' cubic feet of water and v_e the velocity calculated on the basis of the reduced diameter, d_e, obtained from tables or curves of experience similar to those in Figure 7. The complete equations are $S' = 0.56\, d_e^{-1}\, v_e^2$ and $G' = 0.952\, D_e^{2.50}\, S'^{0.50}$. In the case of a pipe with effective diameter $d_e = 1$ in. and $S' = 10$, a value of $C_w = 100$ in the Hazen-Williams equation gives the same discharge as this formula, providing an original diameter of 1.1 in. is employed in the Hazen-Williams formula.

The uncoated *steel* and *wrought-iron* pipes had values of n close to 2.00 during their entire service periods. For these pipes the following equation, therefore, holds:

$$s' = Mv^2_e$$

$$\text{where } M = 0.00056\, d_e^{-1}$$

Again, s' is the hydraulic slope after a definite service period, and d_e is obtained from experimental curves. This equation, it will be seen, is identical with that of the hot-water galvanized group. The complete equations, therefore, are also the same.

In closing this formulation of hydraulic service characteristics, it should be noted that the progressive changes in the values of n and d_e/d with service, presented in the discussion, apply for conditions peculiar to this investigation. The restrictions in the application of the tables of Hazen-Williams coefficients, discussed earlier in the paper, hold also for the use of n and d_e/d and for the formulas based upon their use.

Oxygen Drop during Flow through Pipes of Different Materials. During the early part of the investigation a number of determinations were made of the drop in oxygen content of cold water during passage through the pipes of the two cold-water batteries. For these determinations water samples were collected at the piezometer rings during service, and their oxygen content was obtained by the standard Winkler method. More than 100 samples were taken. Although the data are not extensive, it is interesting to note that the results are similar in their order of magnitude to those obtained in the hydraulic tests. The high-copper pipes showed the lowest oxygen drop; the galvanized pipes were next in order, whereas the plain wrought-iron and steel pipes were associated with the greatest oxygen drop. Comparing the results on the basis of pipe diameter, the following average values were obtained:

Class.	Oxygen Drop in p.p.m.	
	¾-in. Pipe.	1½-in. Pipe.
High Copper	.16	.08
Galvanized Iron	.25	.14
Iron	.54	.33

The smaller pipes showed a greater oxygen drop, thus confirming the conclusions from the hydraulic tests as to the effect of pipe diameter upon the speed of reduction in carrying capacity with service.

Physical Appearance of Pipes at the End of the Tests. At the conclusion of the study, the test pipes were removed, and sections were split longitudinally in order that an examination might be made of their interior surfaces. Photographs of the sections are shown in Figures 9, 10 and 11. A visual examination of these photographs leads to the same conclusions, with respect to the relative service characteristics of the seven pipe materials, that were reached from the results of the hydraulic tests. A brief description of the physical appearance of cleaned and uncleaned specimens of each pipe is given in the following schedule. For purposes of comparison the hydraulic findings at the end of the tests are included.

Cold-water Pipes.

1½-in. and ¾-in. Diameter.

1. Copper Pipes.

Uncleaned surface: Thin olive-brown coating; occasional deposits scarcely visible to the eye; smooth.

Cleaned surface: Smooth; no evidence of pitting.

	1½-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	935 000	272 000
C_w	135	130
n	1.78	1.75
d_e/d	1.00	0.99

2. Red-brass Pipes.

Uncleaned surface: Thin olive-brown coating; small greenish deposits, smooth.

Cleaned surface: Slight dezincification; shallow pits.

	1¼-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	927 000	269 000
C_w	133	132
n	1.75	1.77
d_e/d	1.00	1.00

3. Admiralty-metal Pipes.

Uncleaned surface: Thin olive-brown coating; dense small deposits; slightly rough.

Cleaned surface: Marked dezincification; well-scattered pits.

	1¼-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	920 000	267 000
C_w	129	128
n	1.85	1.80
d_e/d	1.00	0.99

4. Galvanized-steel Pipes.

Uncleaned surface: Thick light-brown coating of iron and zinc products; slightly rough.

Cleaned surface: Dark grey; zinc coating almost gone; few small pits.

	1¼-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	960 000	268 000
C_w	126	94
n	1.86	1.99
d_e/d	0.99	0.90

5. Galvanized Wrought-iron Pipes.

Appearance much the same as that of galvanized-steel pipes.

	1¼-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	948 000	243 000
C_w	127	102
n	1.94	1.92
d_e/d	1.02	0.91

6. Steel Pipes.

Uncleaned surface: Heavy brown coating of rust; large tubercles scattered uniformly over the surface.

Cleaned surface: Dark grey; irregular pits varying in depth.

	1¼-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	472 000	126 000
C_w	38	24
n	1.99	1.97
d_e/d	0.66	0.54

7. Wrought-iron Pipes.

Appearance much the same as that of steel pipes.

	1¼-in. Pipe.	¾-in. Pipe.
Q'-cu. ft.	500 000	126 000
C_w	37	28
n	1.97	1.92
d_e/d	0.65	0.57

Hot-water Pipes.

$\frac{3}{4}$ in. Diameter.

1. Copper Pipe.

Appearance much the same as that of cold-water pipes.

Q'-cu. ft.	95 800	n	1.73
C_w	130	d_e/d	1.00

2. Red-brass Pipe.

Appearance much the same as that of cold-water pipes, but dezincification and pitting absent. (Note difference in service period.)

Q'-cu. ft.	14 800	n	1.75
C_w	132	d_e/d	1.00

3. Admiralty-metal Pipe.

Appearance much the same as that of cold-water pipes.

Q'-cu. ft.	13 700	n	1.72
C_w	133	d_e/d	1.00

4. Galvanized-steel Pipe.

Appearance much the same as that of cold-water pipes.

Q'-cu. ft.	11 700	n	1.98
C_w	91	d_e/d	0.89

5. Galvanized Wrought-iron Pipe.

Appearance much the same as that of cold-water pipes.

Q'-cu. ft.	31 900	n	2.00
C_w	76	d_e/d	0.83

6. Steel Pipe.

Uncleaned surface: Heavy black-brown coating; tubercles almost completely clogging the pipe.

Cleaned surface: Wide, shallow pitting.

Q'-cu. ft.	3 100	n	1.98
C_w	9	d_e/d	0.37

7. Wrought-iron Pipe.

Uncleaned surface: Heavy black-brown coating; tubercles almost completely clogging the pipe.

Cleaned surface: Irregular, deep pitting.

Q'-cu. ft.	2 900	n	2.00
C_w	6	d_e/d	0.31

General Summary of Hydraulic Service Characteristics. The range in the hydraulic characteristics C_w, n and d_e/d observed during service is presented in Table 7 together with the generalization of the flow characteristics developed in the body of this paper. This table permits a comparison of the hydraulic histories of the different pipes and summarizes the experience obtained in our study. As previously indicated, use of the values and formulas presented is subject to the limitations of the test conditions.

TABLE 7.— GENERAL SUMMARY OF HYDRAULIC SERVICE CHARACTERISTICS.

Pipe Material.	Diameter in.	Observed Range in.					Generalization Indicated by Tests.		
		Temperature °F.	Water Delivery cu. ft.	C_w*	n	d_e/d	Service delivery up to which Generalization Applies. cu. ft.	C_w	Flow formula.
Copper	1½	36–77	916 000	137–133	1.73–1.79	1.01–0.99	1 000 000		(Note: Hazen-Williams Formula $G=0.00675\ C_w\ D^{2.63}\ S^{0.54}$)
	2	36–77	265 000	154–129	1.73–1.77	1.06–0.99	300 000		
	2½	140	94 000	132–128	1.69–1.75	1.00–0.99	100 000		
Red Brass	1½	36–77	908 000	136–133	1.73–1.77	1.00	1 000 000	130	$G=0.822\ D^{2.71}\ S^{0.57}$
	2	36–77	263 000	155–132	1.72–1.77	1.07–1.00	300 000	(Cold Water)	(Cold Water)
	2½	140	14 000	132	1.74–1.75	1.00	100 000	145	$G=0.930\ D^{2.71}\ S^{0.57}$
Admiralty Metal	1½	36–77	901 000	135–129	1.76–1.85	1.00–0.99	1 000 000	(Hot Water)	(Hot Water)
	2	36–77	260 000	155–128	1.72–1.81	1.07–0.99	300 000		
	2½	140	13 000	133–132	1.72–1.75	1.00	100 000		
Galvanized Steel	1½	36–77	941 000	134–126	1.79–1.94	1.03–0.99	1 000 000		
	2	36–77	262 000	140– 94	1.78–2.00	1.02–0.90	200 000	115	$G=0.780\ D^{2.60}\ S^{0.53}$
	2½	140	8 000	117– 91	1.98–2.00	0.92–0.89	.....	(Cold Water)	(Cold Water)
Galvanized Wrought Iron	1½	36–77	929 000	131–120	1.83–1.98	1.03–0.99	1 000 000		$G'=0.952\ D_e^{2.60}\ S'^{0.50}$
	2	36–77	237 000	114– 88	1.86–2.00	0.95–0.88	200 000	.....	(Hot Water)
	2½	140	31 000	109– 76	1.90–2.00	0.91–0.83	.....		
Steel	1½	36–77	465 000	135– 38	1.79–2.00	1.00–0.66	.....		
	2	36–77	124 000	129– 24	1.77–2.00	0.99–0.54	.....		
	2½	140	3 000	124– 9	1.89–2.00	0.96–0.37	.....		
Wrought Iron	1½	36–77	493 000	129– 37	1.74–2.00	1.00–0.65	.....	.....	$G'=0.952\ D_e^{2.50}\ S'^{0.50}$
	2	36–77	124 000	138– 28	1.76–2.00	1.03–0.57	.....		
	2½	140	3 000	122– 6	1.77–2.00	0.96–0.31	.....		

*Average value for velocities of 1, 2 and 3 ft. per second and temperature of 59° F.
G = Discharge in g.p.m.; G' = Discharge in g.p.m. after a service delivery of Q' cu. ft. of water.
D = Diameter in in.; D_e = Effective diameter in in.
S = Hydraulic slope in ft. per 1 000 ft.; S' = Hydraulic slope in ft. per 1 000 ft. after a service delivery of Q' cu. ft. of water.

Acknowledgements. In closing, the authors wish to acknowledge the generous support given them in their studies by the Copper and Brass Research Association, the various manufacturers whose pipes were employed in the tests, the Hersey Meter Company, the Cambridge Water Board, the Superintendent of Water Works, Timothy Good, and the staff of the Cambridge Filter Plant. The tests, calculations and analyses of results were performed, under the direction of the senior authors, by the junior author and form part of a thesis submitted by him to the Department of Sanitary Engineering of the Harvard Engineering School in partial fulfillment of the requirements for the degree of Doctor of Science in Engineering. T. F. Hatch, Instructor in Sanitary Engineering in the Harvard Engineering School, assisted in the preparation of the paper.

PROCEEDINGS.

FORTY-NINTH ANNUAL CONVENTION.

ATLANTIC CITY, N. J.

September 23–26, 1930.

The following is a synopsis of such parts of the proceedings at the Atlantic City Convention as appear to be of value for the record.

The Forty-ninth Annual Convention of the NEW ENGLAND WATER WORKS ASSOCIATION was held at Atlantic City, N. J., September 23–26, 1930.

The technical sessions of the convention were held in the Viking Room of Haddon Hall, the exhibits of the Associates being placed in the adjoining rooms.

President Robert Spurr Weston presided at the meetings.

TUESDAY, SEPTEMBER 23.

Morning Session.

THE PRESIDENT. The Forty-ninth Annual Convention will come to order. We are fortunate in having Acting Mayor Paxson to welcome us to Atlantic City. Mayor Paxson.

ADDRESS OF WELCOME BY ACTING MAYOR JOSEPH A. PAXSON.

Mr. President and members, friends and visitors of the NEW ENGLAND WATER WORKS ASSOCIATION: Atlantic City is proud to welcome this body of men. We are glad that you have selected our wonderful city for your convention city. Cities may come and cities may go, but water works stay with us from the beginning to the end. Without expert sanitary chemists and engineers, no city would be able to survive. You men have chosen as your profession one of the noblest things that any man can do. It is men of your type who make it possible for cities to exist and to be healthy and prosperous.

Mr. President, I welcome you on behalf of the citizens of Atlantic City, and hope that your stay among us will be beneficial to you and yours. We invite you to come back at your earliest convenience. I thank you. (*Applause.*)

ADMINISTRATIVE REPORTS.

The Annual Reports of the Secretary, Treasurer, and Editor were submitted by Frank J. Gifford, Albert L. Sawyer and Gordon M. Fair, respectively. (See page 543.)

The Report of the Finance Committee was read by the Secretary. (See page 552.)

Upon motion from the floor, duly seconded, it was voted to accept these reports and place them on file.

Award of Dexter Brackett Memorial Medal.

THE PRESIDENT. The Dexter Brackett Memorial Medal was presented to the Association by a former member and past president of this Association who, in addition to being of a generous and kindly nature, was a man of eminent attainments in the water-works field. He was one of Boston's triumvirate of great water-works builders; Messrs. Stearns and FitzGerald being the other two.

Will Mr. Cairns, of Waterbury, who is to be the recipient of the medal today, come to the platform? I will ask Mr. Macksey to escort him.

(*Mr. Cairns is escorted to the platform by Mr. Macksey.*)

Robert Andrew Cairns needs little introduction to you. He is a member of our Executive Committee. But for those who are not acquainted with his work I shall say a few words about him. Mr. Cairns was born in Waterbury, Conn., a great many years ago, and was educated in the public schools and at Rensselaer Polytechnic Institute. After graduating in 1885, and after having instructed in that school for a year and worked with the Ludlow Valve Manufacturing Company for a year, he went to Maryland and Delaware, where he engaged in water-works construction. Coming back to Waterbury in 1890, he became city engineer, and he is city engineer today after nearly forty years of service.

Mr. Cairns not only has been engaged in his work as city engineer, but also has done a great deal of consulting work for Connecticut municipalities and for Connecticut manufacturers.

During his period of office, Waterbury, as you know, has developed from a very small city into the center of metal manufacturing, of which the manufacturing of brass and copper articles is of chief importance. I am told by friends in Waterbury that not only has Mr. Cairns been interested in the physical growth of the city but in its higher life as well.

It is in the water works of Waterbury that we note chiefly his service to his community. He has constructed, among other things, a large masonry dam called the Wigwam Dam, and a large earthen dam, and, lastly, the Shepaug Tunnel, which brought water to reënforce the rapidly growing city through the mountain which intervened between the old works and the new.

I have great honor, Mr. Cairns, in presenting you with the Dexter Brackett Memorial Medal, and hope you will consider it a token of our appreciation of your long time service. (*Applause.*)

ROBERT ANDREW CAIRNS. Mr. President, it is with much pleasure that I accept this award at your hands, deeply appreciating the honor done

me by the Committee on Award and the approval of its action by the Executive Committee of the Association.

There may be some doubt as to whether my story of the Shepaug Tunnel building deserved such recognition, but there can be no doubt that the award will be taken as a distinguished honor and that the medal will be highly prized.

I want also to thank the members of the Association for coming to Waterbury and showing so much interest in the efforts we have been making to secure an adequate supply of potable water for the future needs both of our own and adjoining communities. The attendance at that meeting in Waterbury on April 10, 1929, was unusually large in spite of the inclement weather, and the whole occasion is remembered with great pleasure by every one connected with the water department of the city.

When I was beginning my work in water-supply engineering, the NEW ENGLAND WATER WORKS ASSOCIATION was enjoying a sort of golden age, or so it has always seemed to me. At that time the accomplishments of such men as Alphonse Fteley, Frederick P. Stearns, Desmond FitzGerald, Dexter Brackett, and in the Massachusetts State Board of Health Dr. Thomas Drown, were placing eastern Massachusetts and this Association in the very forefront of water-supply science both as to adequacy and dependability of supply and as to quality of the water furnished. I had at the beginning of my career the tremendous advantage of knowing these men and learning from them, and I have always attributed to them the impulse to go ahead on correct lines which led to such success as I have had.

It follows naturally that the NEW ENGLAND WATER WORKS ASSOCIATION has always held a preëminent position in my estimation, and its great names have always had my admiration and respect.

Dexter Brackett was one of these great men whose ability in his profession and interest in our Association was so fittingly commemorated by the establishment of this memorial.

In accepting this medal, I do so with great regard for the ability and character of Dexter Brackett, and with sincere appreciation of the action of the Committee in numbering me among those permitted to possess such a memorial of this eminent man. (*Applause.*)

CLOSING OF POLLS.

THE PRESIDENT. The polls have closed and tellers will be appointed to count the ballots, the result of the election to be announced at a later business meeting.

At the Executive Committee meeting which was held following the morning session, the following members and associates were elected:

Members: George F. Wieghardt, West Englewood, N. J.; William A. Hardenbergh, New York City; Thomas R. Camp, Cambridge, Mass.; Thomas H. Casey, Clinton, Mass.; Russell W. Cronk, Dedham, Mass.;

William B. Duffy, North Andover, Mass.; William S. Hayward, West Roxbury, Mass.

Associates: Joseph G. Pollard Company; Wailes Dove-Hermiston Corporation; Pardee Engineering Company; Charles L. Shea, East Dedham, Mass.; McEverlast, Inc.; Vost Brothers Manufacturing Company; Grant Manufacturing Company (reinstated).

TUESDAY, SEPTEMBER 23.

Afternoon Session.

COMMITTEE REPORTS.

Alfred O. Doane, Chairman of the Committee on Painting Standpipes, presented the report of his Committee. (See page 553.) It was voted that the report of the Committee be accepted and the Committee discharged.

A progress report of the Committee on Water-main Disinfection was read by E. Sherman Chase, Chairman of the Committee. (See page 565.)

A progress report of the Committee on Standard Specifications was made by C. W. Mowry, Chairman of the Committee. (See page 568.) The report covered the following: (1) Standardization of Small Hose Threads; (2) Standardization of Cast-iron Pipe and Special Castings; (3) Simplification of Manhole Frames and Covers; (4) Standardization of Pipe Flanges and Fittings; (5) Code for Pressure Piping.

A paper, "Disinfection of the Wanaque Aqueduct," by Attmore E. Griffin, Analyst, North Jersey Water Supply Commission, Newark, N. J., was read by E. Sherman Chase, and discussed by him.

A paper, "Recent Developments in Chlorination," was read by Francis D. West, Manager of Sales, Paradon Manufacturing Company, Arlington, N. J. Linn H. Enslow and Robert Spurr Weston discussed the paper.

A paper, "Hydraulic Service Characteristics of Small Metallic Pipes," by G. M. Fair, M. C. Whipple and C. Y. Hsiao, was read by Gordon M. Fair, Associate Professor of Sanitary Engineering, Harvard University, Cambridge, Mass., and was discussed by Richard H. Ellis, C. W. Mowry, A. O. Doane, J. R. Birkenbine, Samuel H. MacKenzie and Roger W. Esty.

A paper, "How Small Cast-iron Pipe is Made and Used," was read by J. R. McWane, President of the McWane Cast Iron Pipe Company, Birmingham, Ala. C. W. Mowry, Roger W. Esty and J. T. Robertson took part in the discussion.

TUESDAY, SEPTEMBER 23.

Evening Session.

By courtesy of the Water Works Manufacturers Association, Inc., a reception and dance was given at Haddon Hall Hotel.

WEDNESDAY, SEPTEMBER 24.

In the morning a party left Atlantic City by special train for Florence and Burlington, N. J. At Florence, an inspection was made of the plant of R. D. Wood & Company. At Burlington, luncheon was served and the U. S. Cast Iron Pipe & Foundry Plant was inspected. The trip and luncheon were arranged by the Water Works Manufacturers Association, Inc.

WEDNESDAY, SEPTEMBER 24.

Evening Session.

Superintendents' Session.

Subjects of especial interest to superintendents were discussed as well as matters affecting the welfare of the Association. Henry D. Macksey presided. The following members took part in the discussions: Henry T. Gidley, Samuel H. MacKenzie, Roger W. Esty, Patrick E. Kelley, William A. MacKenzie, George F. Merrill, Howard M. King, Stephen H. Taylor, W. C. Hawley, E. Sherman Chase, Hugh McLean, C. W. Mowry, Percy R. Sanders, W. P. Mosteller, Edwin H. Arnold, Henry A. Symonds, Secretary Gifford, George A. Caldwell and Morris R. Sherrerd.

THURSDAY, SEPTEMBER 25.

Morning Session.

A paper, "Copper and Health," was read by William G. Schneider of the Research Department of the Copper and Brass Research Association, New York, N. Y.

A paper, "The Atlantic City Water Works," was read by Lincoln Van Gilder, Engineer and Superintendent of Water Works, Atlantic City, N. J. W. C. Hawley and A. O. Doane discussed the paper.

A paper, "Modern Aspects of Color Removal," was read by A. S. Behrman, Chemical Director, International Filter Company, Chicago, Ill.

A paper, "The Submarine Pipe-line between Portland, Me., and Great Diamond Island," was read by Harry U. Fuller, Chief Engineer, Portland Water District, Portland, Me.

A paper, "A New Development in Wrought-iron Pipe Manufacture," was read by Dr. James Aston, Consulting Metallurgist, A. M. Byers Company, Pittsburgh, Pa.

A moving picture entitled "The Story of Anaconda," dealing with the production of copper pipe from mine to consumer, was shown.

THURSDAY, SEPTEMBER 25.

Afternoon Session.

Morris R. Sherrerd, Chief Engineer, State Water Policy Commission, Newark, N. J., explained the general water-supply situation of Northern New Jersey.

A paper, "The New Wanaque Water Supply," was read by Arthur H. Pratt, Consulting Engineer, Newark, N. J. Morris R. Sherrerd discussed the paper.

A paper, "Methods Attempted for Prevention of Phenol and Other Tastes in Water Supply at Rahway, N. J.," was read by Mortimer M. Gibbons, Water-works Chemist, Rahway, N. J. A. S. Behrman discussed the paper.

THURSDAY, SEPTEMBER 25.

Evening Session.

On Thursday evening a smoker and entertainment were given at Haddon Hall through the courtesy of the Water Works Manufacturers Association, Inc.

FRIDAY, SEPTEMBER 26.

Morning Session.

Report of Tellers of Election.

Total number of ballots cast 281

President.

GEORGE H. FINNERAN 277

Vice-President.

RICHARD H. ELLIS 272

Directors.

HOWARD M. KING 269
HENRY F. HUGHES 269

Treasurer.

ALBERT L. SAWYER 272

(*Signed*) CHARLES J. CRUMP, *Chairman.*
H. W. DOTTEN,
ROGER W. ESTY.

THE PRESIDENT. It is my duty, as my last act of office, to announce the election of these gentlemen, particularly that of Mr. Finneran, as president. I hope he will enjoy the contacts with this excellent group of water-works officials as well as I have. The NEW ENGLAND WATER WORKS

ASSOCIATION will celebrate its Fiftieth Anniversary next year, and I know of no more fitting president to lead us through the exercises of that time than the man to whom I have the honor of turning over the office at this time. Mr. Finneran. (*Applause.*)

GEORGE H. FINNERAN. Mr. President and fellow members: I wish to thank you for the honor you have conferred on me in making me your president for the coming year. It is not only an honor but an expression of the confidence that you have in my ability to carry on and conduct the affairs of the Association with the same success as my predecessors. I hope that I shall measure up to their performance. This I cannot do without the help and coöperation of my fellow members, but I feel confident that I shall have it, with the result that the Association will achieve its object,— that is, service of value to the members, and through them to the larger group, the general public. I thank you. (*Applause.*)

The president read his address. (See page 540.)

(*Adjourned.*)

President's Address.

Our Successors.

By Robert Spurr Weston.*

No one who is as well acquainted with the good works of this Association as is a retiring President can subject them to destructive criticism. When one recalls the names of such superintendents as Coggeshall, Chace, Batchelder, Brooks, Walker, Stacey, Martin and Holden; such engineers as Stearns, Brackett, FitzGerald, Coffin, Noyes, Metcalf and Hazen; and such scientists as Sedgwick, Whipple and Drown, all of them products and parts of the organization's past, a member who does not behold the Association with admiration is blind indeed.

Neither is the social side of the Association's life to be lost sight of. The gathering together of responsible people,— managers, material men, engineers and scientists,— engaged in a worthy occupation, is agreeable, broadening and stimulating, and the speaker knows of no organization of its kind where the finer human qualities are more in evidence.

The permanent record of the Association's work,— its Journal,— is a matter of pride to all, as it tells a story of nearly fifty years of progress.

Yet, with all these accomplishments, of which we are proud, many are wondering about the future work of the Association, and among them is your retiring President who, feeling compelled by custom to address you, may be pardoned if he speaks his mind on this topic. It seems a fitting time to consider the work of the Association in the light of our highly industrialized modern life, and whether or not our "old wine should be put into new bottles."

As one looks over the heads of those present at this convention, or at a monthly meeting, one is impressed with the high average age of those in attendance. There seem to be many "old men for counsel" but few "young men for war." Particularly noticeable is the high average age among the superintendents. While this is an impression which may be disproved by statistics, the speaker can but give voice to it.

While the absence of the younger men may be variously explained — as by finances, the desire of the "super" or the "chief" to leave responsible subordinates at home on the days of meeting, or the shortsightedness of water-works departments and owners,— the fact remains that there are far too many water-works men and too many young water-works men who fail to profit by taking part in the proceedings and enjoying the personal contacts which the meetings engender. Rather disturbing, also, is the slow growth in membership.

Another difficulty under which the Association labors is the preparation of programs. "Too technical," say some, of the papers giving the results of years of research, and which are valuable for the reputation of our

* Consulting Engineer, Boston, Mass.

JOURNAL. "Little of permanent value," say others, of so-called topical discussions; "Tiresome," say others, of descriptions of new works, detailed, carefully worded and valuable as a record of experience.

Unfortunately, the criticisms are true, and more unfortunately, human nature must be changed before the programs can be changed so that all papers will be equally pleasing to everyone. Rare are men like Whipple who could make microörganisms live in our minds, as we regret they do in many of our reservoirs; or, like Forbes whose experiences are real contributions to the art of water supply; and like Freeman whose descriptions of engineering projects hold the rapt attention of listeners of all kinds.

In some water-works associations, notably the American Water Works Association, an attempt has been made to solve this problem by the formation of sections, or divisions; for example, one for those interested in water purification and water analysis, and one for those interested in water-works accounting. While giving the members a choice of papers to hear, and avoiding some of the difficulties which the program committee always faces, it seems to the speaker that the segregation of managers, engineers, accountants and analysts, and all the other kinds of water-works men into groups would cause the loss of much of value which this Association now possesses.

The word "association" implies a "togetherness" which would be greatly weakened by subdividing it into technical units. Many societies now exist where the chemist, the accountant, the insurance expert, or the engineer can present highly technical papers on the latest results of research, but this is a water-works association where the give and take between the student and the worker, between buyer and seller, between manager and operator, should be as great as practicable. It must not become a mere market place or social club, valuable as these features are.

Every program committee has met the criticism that too many papers are written by engineers and other technicians, and too few by superintendents or those who talk their language. This is true and probably truer than it was in the past. Every program committee makes a sincere effort to secure papers which describe the experiences of those directly connected with water works and their management, but the effort often bears relatively little fruit. Most of the papers offered are those by ambitious young men, anxious to establish their professional reputation by the publishing of the results of their work. Less easily obtainable are descriptive accounts of engineering works by their designers. Hardest to get are papers on water-works management by superintendents and others.

The speaker does not advocate the lowering of the scientific grade of the presented papers that they may be more widely understood, but that the high standard of our JOURNAL be carefully preserved. He does suggest that much may be accomplished in general understanding if the authors when presenting papers which are more or less technical as they appear in print would modify their style when presenting the papers at the meetings.

It must be admitted, however, that such a presentation demands an author with some genius for instruction or for stating in simple terms the results of research. Few have the ability in this direction which our Past President, William T. Sedgwick, possessed.

Another way of meeting the situation is to broaden the understanding of the younger water-works men, especially those in the lower ranks who are to take the places of their elders. This should be done. They would take a greater interest in the programs of meetings and, in turn, become better material for the superintendents of the future, thus benefiting the Association by increasing the interest of the younger men and giving greater opportunity for service.

The answer to the problem which the speaker suggests is the formation of a water-works school under the patronage of the Association and in co-operation with some technical institute at which short, practical courses could be given annually by well informed superintendents and technical school instructors, at the expense of the student, or better, his department or water company.

The idea is not new. In several states, where there are state universities, short water-works courses have been given for some time past, while short courses in agriculture and other subjects have been given for a generation. At present there is a New England Public Health Institute which meets annually for a week in one of the six New England states and has been of great service in training health officers and sanitary inspectors.

Just how a water-works school should function is, of course, beyond this suggestion, but the speaker hopes that the general idea has enough merit in it to warrant the appointment of a committee to inquire and report regarding the feasibility thereof. Naturally, any plan of this kind would involve work by someone and probably additional help from the Secretary's office and with attendant expense. However, if the gain in membership were considerable and the gain in interest still more, the cost could be forgotten, and the objects of the Association, as stated in the Constitution, namely "the advancement of knowledge relating to water works and water supply, and the encouragement of professional and social intercourse among water-works men" would be more nearly realized.

Annual Report of the Secretary.

Mr. President and Gentlemen of the New England Water Works Association: The Secretary submits herewith the following report of the changes in membership during the past fiscal year, and the general condition of the Association.

The present membership is 822, constituted as follows: 13 Honorary, 698 Members, 0 Juniors, 15 Corporate Members and 96 Associates. The detailed changes are as follows:

MEMBERSHIP.

September 1, 1929.	Honorary Members		14		
	Elected:				
	November, 1929	1	1		
				15	
	Withdrawals:				
	Died			2	
September 1, 1929.	Total Members		701		
	Withdrawals:				
	Resigned	27			
	Dropped	11			
	Died	9	47		
				654	
	Elected:				
	September, 1929	14			
	November, 1929	2			
	December, 1929	4			
	February, 1930	7			
	March, 1930	2			
	June, 1930	13			
			42		
	Reinstated:				
	Resigned in 1917	1			
	Dropped in 1920	1	2	44	698
September 1, 1929.	Total Juniors		0		
September 1, 1930.	Total Juniors		0		0
September 1, 1929.	Total Associates		102		
	Withdrawals:				
	Resigned	6			
	Dropped	4	10	92	
	Elected:				
	September, 1929	1			
	December, 1929	1			
	June, 1930	1	3	3	
	Reinstated:				
	Resigned in 1927–1928		1	1	96
September 1, 1929.	Total Corporates		13		

	Elected:			
	September, 1929	1		
	February, 1930	1	2	15
September 1, 1930.	Total Membership			822
September 1, 1929.	Total Membership			830
	Net loss			8

Members Elected September 1, 1929, to September 1, 1930.

Honorary Members.

November 13, 1929. Sir Alexander C. Houston. (1)

Members.

September 17 to 20, 1929. G. A. Dickel, Richard Dillon, H. P. Eddy, Jr., M. E. Flentje, C. C. Getchell, A. A. Higgins, H. F. Huy, E. W. Kelly, P. F. Kingman, M. G. Mansfield, C. E. Notsley, D. M. Ryan, F. E. Smith, E. A. Tarr. (14)
November 13, 1929. P. S. Wilson, A. D. Couch. (2)
December 12, 1929. J. B. Belknap, E. J. Dionne, H. C. Mandell, D. E. Moulton. (4)
February 12, 1930. A. H. Coy, Thorn Dickinson, E. L. Haskell, J. J. Hill, J. H. Murdoch, Jr., J. L. O'Brien, A. L. Pierce. (7)
March 13, 1930. H. P. Burden, J. F. Sullivan. (2)
June 25, 1930. G. K. Clement, C. E. Durant, M. A. Gilpin, J. J. Knapp, Jr., G. A. Lyons, M. J. Herlihy, R. V. McNamara, W. E. Moore, C. L. Pool, C. H. Poor, E. E. Randall, H. M. Turner, T. A. Kelley. (13)
Reinstated:

Resigned in 1917 (F. D. West)	1
Dropped in 1920 (William Plattner)	1

Associates.

September 17 to 20, 1929. The Atlas Mineral Products of Pennsylvania. (1)
December 12, 1929. Chase Brass & Copper Company, Inc. (1)
June 25, 1930. Phoenix Meter Corporation. (1)
Reinstated:
Resigned in 1927–1928 (Bingham & Taylor Corporation). (1)

Corporates.

September 17 to 20, 1929. New Rochelle Water Company. (1)
February 12, 1930. Marshfield Water Board. (1)

Members.

Died: George Bowers, Guy H. Chase, Charles W. Ellis, George C. Gensheimer, Alfred R. Hathaway, Albert B. Hill, M. J. Mahoney, W. P. Robinson, Elbert Wheeler. (9)
Resigned: Edward Bartow, H. M. Beverly, A. M. Chaffee, G. W. Coffin, H. B. Collins, C. K. Corbin, H. A. Dill, R. G. England, E. J. Guiney, G. G. Honness, H. E. Keeler, T. P. McDermott, E. E. Miller, F. C. Millspaugh, J. W. Money, W. F. Monfort, P. H. Mosher, E. R. Payson, J. H. Read, Kenneth Shibley, F. H. Torrey, E. P. Twomey, W. A. Tripp, R. G. Tyler, C. R. Weagraff, John Young, J. J. Philbin. (27)
Dropped: F. W. Collins, H. F. Cox, L. M. Fisher, Halsey French, D. M. Hatch, J. M. Jones, H. P. Letton, A. C. Libby, G. N. Norris, A. V. Ruggles, A. W. Squires. (11)

Associates.

Resigned: Barber-Greene Company, Dixon Crucible Company, The Federal Meter Corporation, Michigan Valve & Foundry Company, Ware Coupling & Nipple Company, La Motte Chemical Products Company. (6)

Receipts for Fiscal Year, September 1, 1929, to September 1, 1930.

Entrance Fees			$170.00
Annual Dues:			
Members	$3 896.22		
Corporates	140.00		
Associates	1 940.00	$5 976.22	
Fractional Dues:			
Members	$58.50		
Corporates	7.50		
Associates	15.00	81.00	
Past Dues:			
Members	$62.00		
Associates	20.00	82.00	
1930–1931 Dues :			
Members		7.50	
Total dues			$6 146.72
Advertisements			3 747.00
Subscriptions			449.99
JOURNALS sold			104.50
Sundries			1 007.41
Total			$11 625.62
There is due the Association:			
Advertisements		$431.00	
JOURNALS		94.50	
Subscriptions		160.00	685.50
Total			$12 311.12

Respectfully submitted,

FRANK J. GIFFORD, *Secretary*

Annual Report of the Treasurer.

September 1, 1929, to August 31, 1930.

The President and Members of the New England Water Works Association:

I herewith submit my report as treasurer for the year ending August 31, 1930.

Receipts.

September 1, 1929 — Cash on hand			$1 429.19
Initiation fees	$170.00		
Dues	6 146.72	$6 316.72	
Interest and dividends		820.84	
Journal:			
Advertisements	$3 747.00		
Subscriptions	449.99		
Sale of Journals	104.50		
Sale of reprints	69.52		
Sale of cuts	5.57		
Electrotyping	7.75		
Retouching photographs	5.50	4 389.83	
Miscellaneous:			
Certificates of membership	$1.50		
Filtration forms	2.40		
Standard specifications	3.00		
Meter sheets	8.00		
Balance June outings	24.08		
Surplus dinner tickets	59.00		
Affidavit	.25	98.23	
Total receipts			$11 625.62
			$13 054.81

Expenditures.

Journal:			
Advertising agent's salary and commission	$118.40		
Editor's salary	500.00		
Editor's expense	58.50		
Printing	6 607.00		
Reporting	282.94		
Reprints	405.79		
Stationery and postage	73.76		
Sundries	8.20	$8 054.59	
Office:			
Certificates of membership	$.75		
Engineering societies of Boston	2 160.00		
Exchange	3.14		
Printing, stationery and postage	185.32		
Secretary's salary	400.00		
Secretary's expense	101.13		
Treasurer's salary and bond	112.50		
Sundries	42.86	3 005.70	

Meetings and Committees:			
Committee on pipe, share of expense	$400.00		
Badges	49.00		
Dinners for guests	26.00		
Printing, stationery and postage	672.05		
Stereopticon	20.00		
Sundries	186.85	$1 353.90	
Total expenditures			$12 414.19
August 31, 1930 — Cash on hand			640.62
			$13 054.81

Invested Funds.

Invested funds September 1, 1929		$15 622.43
Interest on bonds	$80.00	
Interest on deposits	63.40	
Interest on savings bank deposits	677.44	820.84
		$16 443.27
Interest paid over to the Association		$820.84
Invested funds August 31, 1930		15 622.43
		$16 443.27

The Finance Committee for the fiscal year ending August 31, 1930, recommended a budget of $12 000.

There has been expended during the year $12 414.19, an overdraft of $414.19. This was caused by the greater expense of printing the June number of the JOURNAL. The details are as follows:

	JOURNAL.	Office.	Meetings.
Appropriation	$7 000.00	$3 200.00	$1 800.00
Overdrawn	414.19	.....	.....
Transferred from	.....	194.30	446.10
	$7 414.19	$3 005.70	$1 353.90
Transferred to	640.40	.....	.....
	$8 054.59	$3 005.70	$1 353.90
Expended	8 054.59	3 005.70	1 353.90
Balance	.....	.....	.....

Respectfully submitted,

ALBERT L. SAWYER, *Treasurer.*

TREASURER'S REPORT.

STATEMENT OF RECEIPTS AND EXPENDITURES.

Receipts.		*Expenditures.*	
Cash on hand September 1, 1929	$1 429.19	Bills paid as per vouchers	$12 414.19
Interest on bonds and deposits	820.84	Cash on hand August 31, 1930	640.62
Received from Secretary	10 804.78		
	$13 054.81		$13 054.81

ASSETS AND LIABILITIES.

Assets.			*Liabilities.*	
Cash in banks as per list		$14 448.05	Surplus	$16 948.55
First National Bank	$640.62			$16 948.55
City Five Cents Savings Bank	2 000.00			
Farmers and Mechanics Savings Bank	2 068.46			
Franklin Savings Bank	2 000.00			
Haverhill Savings Bank	2 000.00			
Home Savings Bank	1 011.25			
Mechanics Savings Bank	1 261.19			
Pentucket Savings Bank	2 000.00			
People's Savings Bank	1 466.53			
Bonds Nos. 2642 and 2644 Lake Shore & Michigan So. R.R. 4's due May 1, 1931		1 815.00		
Accounts Receivable		685.50		
Advertisements	431.00			
JOURNALS	94.50			
Subscriptions	160.00			
		$16 948.55		

Annual Report of the Editor.

To the New England Water Works Association: The Editor submits herewith the following report for the year ending August 31, 1930.

As has been customary in the past, the tables of financial figures, accompanying the report, are based upon total charges and accounts receivable, rather than actual cash received or disbursed.

Table 1 is a statement of the material published.

Table 2 gives the receipts and expenditures for the year.

Table 3 is a comparison of the past year with preceding years.

Size. The four issues contained 812 pages, of which 570 were text.

Cost. The gross cost of the Journal was $8 054.59, equivalent to $9.80 per member, and the net cost was $3 664.76, equivalent to $4.46 per member.

Reprints. Fifty reprints of each paper have been furnished to the author where desired.

Circulation. The present circulation of the Journal is:

Members, all grades	822
Subscribers	139
Exchanges	19
Total	980

(Journals *have been sent to all subscribers.*)

Respectfully submitted,

Gordon M. Fair, *Editor.*

EDITOR'S REPORT.

TABLE 1.

Statement of Material in September and December, 1929, and March and June, 1930, Issues of the Journal of the New England Water Works Association.

Date.	Pages of.								
	Papers.	Proceedings.	Total Text.	Index.	Advertisements.	Cover and Contents.	Insert Plates.	Total.	Total Cuts.
September, 1929	79	41	120	0	53	5	2	180	15
December, 1929	85	5	90	10	53	5	0	158	8
March, 1930	156	0	156	0	49	5	6	216	118
June, 1930	195	9	204	0	49	5	0	258	0
Total	515	55	570	10	204	20	8	812	141

TABLE 2.

RECEIPTS AND EXPENDITURES ON ACCOUNT OF SEPTEMBER AND DECEMBER, 1929, AND MARCH AND JUNE, 1930, ISSUES OF THE JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION.

Receipts.		*Expenditures.*	
Advertisements	$3 747.00	Reporting	$282.94
Subscriptions	449.99	Printing	6 607.00
Sale of JOURNALS	104.50	Stationery and postage	73.76
Sale of reprints	69.52	Reprints	405.79
Sale of cuts	5.57	Editor's salary	500.00
Electrotyping	7.75	Editor's incidentals	58.50
Retouching	5.50	Advertising agent's salary and commissions	118.40
	$4 389.83	Sundries	8.20
Net cost of JOURNAL	3 664.76		
	$8 054.59		$8 054.59

EDITOR'S REPORT.

TABLE 3.

COMPARISON OF JOURNALS OF THE NEW ENGLAND WATER WORKS ASSOCIATION.

	Vol. XXXIV. 1920.	Vol. XXXV. 1921.	Vol. XXXVI. 1922.	Fiscal Year Ending Aug. 31, 1924. 4 issues.	Fiscal Year Ending Aug. 31, 1925. 4 issues.	Fiscal Year Ending Aug. 31, 1926. 4 issues.	Fiscal Year Ending Aug. 31, 1927. 4 issues.	Fiscal Year Ending Aug. 31, 1928. 4 issues.	Fiscal Year Ending Aug. 31, 1929. 4 issues.	Fiscal Year Ending Aug. 31, 1930. 4 issues.
Average edition (copies printed)	1 130	1 150	1 100	1 100	1 100	1 100	1 100	1 138	1 200	1 350
Average membership	885	864	826	764	755	775	784	808	831	822
Circulation at end of year	970	929	929	880	873	906	916	955	993	980
Pages of text	359	399	618	404	421	523	492	528	507	570
Pages of text per 1 000 members	406	462	748	529	558	675	628	654	610	693
Total pages, all kinds	520	560	801	611	644	761	724	769	745	812
Total pages per 1 000 members	588	648	970	800	853	982	952	952	896	988
GROSS COST:										
Total	$5 011.03	$5 381.84	$6 354.10	$4 783.60	$5 272.91	$6 524.62	$5 839.36	$6 849.44	$6 740.87	$8 054.59
Per page	9.64	9.61	7.93	7.83	8.19	8.57	8.07	8.91	9.06	9.92
Per member	5.66	6.23	7.69	6.26	6.98	8.42	7.45	8.48	8.12	9.80
Per member per 1 000 pages	10.88	11.12	9.60	10.25	10.84	11.07	10.29	11.02	9.77	12.07
Per member per 1 000 pages text	15.77	15.61	12.47	15.50	16.58	16.10	15.13	16.06	16.01	17.19
NET COST:										
Total	$1 722.14	$1 869.85	$2 434.26	$561.51	$943.40	$2 040.28	$710.63	$1 716.25	$1 857.58	$3 664.76
Per page	3.31	3.34	3.04	0.92	1.46	2.68	.98	2.23	2.07	4.51
Per member	1.95	2.16	2.95	0.74	1.25	2.64	.91	2.12	2.24	4.46
Per member per 1 000 pages	3.75	3.87	3.68	1.20	1.94	3.47	1.26	2.76	2.50	5.49
Per member per 1 000 pages text	5.43	5.43	4.77	1.82	2.97	5.05	1.85	4.02	4.41	7.82

REPORT OF FINANCE COMMITTEE.

To the Executive Committee of the
New England Water Works Association.
Gentlemen:

The Finance Committee has examined the books and accounts of the Secretary and the Treasurer for the fiscal year ending August 31, 1930, and finds them correct.

The Committee submits the following budget for the fiscal year ending August 31, 1931:

	Expended. 1929–1930.	Recommended. 1930–1931.
JOURNAL	$8 054.59	$8 000.00
Office	3 005.70	3 100.00
Meetings and committees	1 353.90	1 600.00
Publication of Constitution, By-Laws and List of Members	.....	300.00
	$12 414.19	$13 000.00

The amount expended for the JOURNAL during the past year was about $1 300 more than the previous year because of the publication of tables of Rainfall in New England. The amount recommended for the JOURNAL this year includes the publication of an Index which has not been published for many years. It seems desirable to have this done as well as the publication of the Constitution, By-Laws and List of Members.

The receipts for the year ending September 1, 1930, were $11 625.62. The receipts for the fiscal year ending September 1, 1931, as estimated, will be $11 100. The budget, $13 000, therefore, exceeds the estimated receipts by about $2 000. However, as the Association has over $16 000 in cash and quick assets, the Committee believes that the proposed budget is reasonable and the publication of the Index and List of Members is imperative.

Respectfully submitted,

THEODORE L. BRISTOL,
JOHN L. HOWARD,
HENRY T. GIDLEY,
Finance Committee.

August 30, 1930.

REPORT OF THE COMMITTEE ON PAINTING STANDPIPES.

August 12, 1930.

To the New England Water Works Association:

The Committee on Painting Standpipes submits the following report:

The information on which this report is based was obtained from answers to a questionnaire which was sent to persons having control of standpipes and to others who were in a position to furnish information concerning the subject. Valuable information was received also from the Bureau of Standards and from books, articles and papers on corrosion and painting.

The problem of protecting the outside of a standpipe does not differ materially from that of other steel structures, but as the inside is exposed to water of constantly varying depth and, in the northern part of the country, to abrasion from ice, effective protection of the interior surfaces of steel standpipes against corrosion is difficult. The corrosion of iron and steel has been the subject of much investigation, and many theories have been proposed to account for this destructive action. The weight of evidence seems to prove that corrosion is due to electro-chemical action.

Standpipe Materials.

Standpipes are generally constructed of basic open-hearth steel plates and steel rivets, as this material is cheaper and stronger than wrought iron and can be obtained in larger plates.

Before steel came into general use, many standpipes were built of wrought iron, and some of these structures are still in service. The relative corrosion of wrought iron and steel has been the subject of numerous investigations, and while instances have been found in which one or the other of these materials seemed to show a marked superiority, the results in general indicate that in fresh water and under equal conditions there is no great difference in the rate of corrosion of the two materials.

Careful investigations also indicate that there is little if any difference in relative corrosion between the various grades of steel plates commonly used in the construction of standpipes. Copper-bearing steel containing from 0.10 to 0.25 per cent. of copper has shown a marked superiority over ordinary steel in resistance to corrosion in atmospheric exposure, but little if any difference in this respect in under-water or underground conditions.

Steel may be rendered practically immune to corrosion by the addition of chromium. The cost, however, makes its use prohibitive in standpipe construction.

Treatment of Plates at the Mill. The plates as they come from the rolls are covered with a thin blue mill scale; if this coating could be maintained

unbroken it would protect the plate from corrosion; it is, however, quite brittle, and much of it is removed in fabrication.

It is sometimes specified that the plates shall be coated with oil or painted before shipment. There are several objections to this procedure. Among them are the following: (1) the paint is sure to be badly abraded by shipment, and by handling during erection; (2) a double thickness of paint at each riveted joint will be partially burned away by the heat of the rivets; (3) sufficient paint will be left to make it difficult to secure a permanently tight joint; (4) if, as is usual, the riveting is done with air hammers the plates are subjected to severe vibration which loosens the scale under the paint so that it will eventually come off in strips or patches with the scale still adhering to the back of the paint film; (5) finally, if the standpipe is to be sandblasted after erection this paint film will greatly interfere with this operation and may have to be removed by burning or scraping.

Pickling the plates in dilute sulphuric acid to remove the mill scale is sometimes required. This is done in the following manner: All grease and oil are removed by a caustic soda bath. The plates are then immersed in warm water containing from 5 to 10 per cent. of sulphuric acid and afterwards washed with hot water and neutralized in an alkaline bath. Under shop conditions this is a process difficult to control, and it is probable that all traces of these reactions will not be removed, thus causing more trouble than if the mill scale had remained on the plate. The plates rust in a very short time after pickling and must be protected by a priming coat of some kind applied immediately. This, as previously noted, is subject to the disadvantages of a shop coat.

Preparation of the Steel for Painting after Erection. Much of the mill scale is removed in bending the plates and in the riveting operations, especially if air hammers are used. Before the standpipe is completed, considerable rust is generally formed on the plates, but when the plates are cleaned, the rust and the remaining mill scale are removed completely, if the cleaning is done thoroughly. Cleaning is accomplished more expeditiously and more conveniently by the sand-blast process than by the more laborious scraping and wire-brushing method, although when power-driven revolving wire-brushes are used, the results compare favorably with sand blasting. Hand-cleaning methods are slower but produce good results if the work is done carefully.

The surface, produced by the sand blast on new steel plates free from rust pits, is exceedingly smooth. This makes it somewhat difficult to prevent sagging and running of the paint film. The sandblasted surface also rusts almost instantly after cleaning, if the air is moist. The slightly roughened surface produced by the wire brush favors the adherence of the first coat of paint to the steel, and does not rust so quickly as a sandblasted surface.

Oil and grease are best removed by gasoline or turpentine.

Rust holds moisture even when it looks dry. If painted over, the rust continues to spread beneath the paint and thus destroys the film. For this

reason, it is of the utmost importance to remove rust as completely as possible.

For the repainting of standpipes, all rust, dirt and loose paint should be removed, and the surface should be free from moisture when the paint is applied. This is equally important in new work. Painting should preferably be done in warm, dry weather; otherwise blisters are likely to occur, or the paint may peel off.

Painting Materials.

Many forms of protective coatings have been used on standpipes. Some are applied cold; others hot. Paints and varnishes are commonly applied cold; bituminous materials may be cut by a proper solvent and applied cold or may be melted and applied hot.

Paints are mixtures of a vehicle, such as a drying oil, mixed with a pigment. Varnishes are made by compounding various gums and resins or asphalts with drying oils at a high temperature; they may be used clear or mixed with pigment to give body and color.

Pigments. Some of the pigments in common use are red lead, sublimed blue lead and white lead; oxides of iron, zinc and titanium; chromates of lead and zinc; and graphite, either natural or artificial.

Aluminum powder, mixed with a good spar varnish, makes a valuable paint for the outside of standpipes. Due to its heat-reflecting property, it keeps the water comparatively cool.

Red lead has been used for a great many years for protecting iron from corrosion in air and under water. On the whole, it has given excellent results. Red lead is made by roasting litharge, PbO, the yellow monoxide of lead, until it takes on more oxygen and turns red; its composition is then Pb_3O_4. It always contains some unaltered litharge; this may vary from 2 to 20 per cent. Red lead which is used for making paste or ready-mixed paint must be practically free from litharge; otherwise it will harden in the container.

Litharge is a powerful drier. If used in considerable quantity in a paint intended for atmospheric exposure, it tends to make the paint film brittle and less durable. For under-water use, however, the hardening action of litharge on the paint film is of decided advantage, as it reduces the tendency of the film to absorb moisture, to swell up and to become slimy and wash off entirely in many cases. This tendency is exhibited also by other paint films which are not thoroughly dry before they are immersed in water. It is probably one of the principal reasons why so many paints fail quickly under water.

Zinc oxide is a valuable pigment, especially for the outside of the standpipe. If used alone, it makes a hard film which has a tendency to crack and scale. It is therefore generally combined with white lead in a proportion of not over 1 part of zinc to 4 parts of lead by weight; this makes an elastic and durable coating.

Chromates of lead and zinc have the property of preventing or retarding the formation of rust. As they are rather costly, they are commonly mixed with a large proportion of other pigments or inert materials in the manufacture of protective coatings for steel. These coatings have given excellent service, particularly for outside work.

Graphite, either artificial or natural, is used either alone or mixed with silica in ready-mixed paints. The graphite has no action on the oil. Its lubricating quality makes for a paint that is easily brushed out to a thin film.

Nearly all pigments are sold in paste form; this has several advantages. The pigments are ground with a small proportion of oil in paint machines; this makes a paste which is easily mixed with oil to form the paint, and the pigment is so fine and so thoroughly incorporated with the oil that it does not readily separate from the vehicle in the paint and can be brushed out to a thin uniform film which dries quickly. Formerly red lead could not be used in this way owing to a high proportion of unaltered litharge which quickly solidified the oil, but it is now made pratically free from litharge and keeps soft for a long time in either paste or ready-mixed paint.

Vehicles. The vehicle most commonly used in paint is linseed oil, either raw or boiled. The oil hardens by absorbing oxygen from the air, forming a tough elastic coating. As raw linseed oil dries very slowly, a drier is added. The drier is made by heating the oil with the oxides of lead, manganese and sometimes cobalt; it is thinned with turpentine or light petroleum products and causes the paint film to dry in a few hours. If too much drier is used, however, the durability of the paint is reduced.

Boiled oil was formerly made by heating the oil in a large kettle with lead and manganese oxides at a temperature of about 500° F. for 5 or 6 hours with continual stirring. This makes a varnish-like product which dries with a high gloss. It has the property, however, of drying quickly on the surface, thus forming a skin which retards the hardening of the oil beneath. This property is especially disadvantageous when boiled oil is used as a vehicle for paints for under-water work, as the surface skin may be dry to the touch but is softened when exposed to water; as the paint underneath the surface skin is soft, the whole coating is eventually destroyed. The remedy is to use a high proportion of pigment, brush it out thin and allow sufficient time for this thin film to become hard all the way through, before another coat of paint is applied. A small proportion of litharge is of great assistance in the hardening process. Boiled oil resists moisture better than raw oil. For this reason it is much used for paint which is to serve under water.

The old-fashioned kettle-boiled oil is now practically out of the market; that now produced is made by heating about 25 per cent. of the oil with salts of lead, manganese or cobalt until thoroughtly incorporated, and then adding this heated oil to the balance of the oil. The mixture is then heated in large tanks by means of steam coils at a temperature considerably less

than that used in the kettle-boiling process. Sometimes air is blown through the oil, giving more body. It is probable that oil treated in this manner does not resist water so well as the kettle-boiled product.

Boiled oil and raw oil are sometimes used together in paint, from one-third to one half of the total oil being boiled oil. In this case no drier is required.

Turpentine and its mineral substitutes are used to thin the oil. As these substances evaporate almost completely when the paint dries, it is possible to apply a paint having a considerably larger proportion of pigment to oil in the hardened film than should be handled if oil alone was used as the vehicle. When turpentine is employed, the film is hard and has little or no gloss. This is an advantage in under-coat work, as the following coat of paint adheres much better to a dull than to a glossy surface and the hardness of the film prevents elastic under-coat cracks in the finish coat.

Bituminous Coatings, Lacquers and Varnishes. Many bituminous materials are used in making coatings, ranging from coal-tar pitch to natural and artificial asphalts.

In making bituminous coatings, for cold application, a volatile solvent, generally a light petroleum or coal-tar distillate, is used to "cut" or dissolve the material. Some asphalt varnishes are made by compounding with linseed oil and driers. Gilsonite, a natural asphalt found in Utah, is used as a base for many protective coatings. It is of a brittle nature and is generally compounded with materials that furnish the required elasticity. Oil asphalt, a product of oils having an asphaltic base, is also widely used. Many of these products are cut with naphtha, benzol or other volatile and inflammable liquids. These are likely to form explosive mixtures with air or to seriously affect workmen if used in confined and unventilated spaces. As a class, these compounds have not been satisfactory for under-water work, but some have given good service when applied over a coat of red-lead paint. Most of them are quick-drying which is of considerable importance in standpipe work.

Bituminous and asphaltic coatings, as a rule, are more durable if melted and applied hot. They are sometimes compounded with ground slate, rock flour, fine asbestos or other inert materials to give more body and stability to the coating when exposed to heat and to decrease its brittleness in cold weather. These coatings generally require a priming coat applied cold before the hot material is put on; this causes the material to adhere much better to the steel. Some of these primers are made with inflammable solvents and are liable to the same dangers as previously mentioned in the case of inflammable paints. Another difficulty, which has occurred when the rust scale on the surface of the steel has not been thoroughly removed before the coating is applied, is that the priming coat seems to gradually loosen the remaining scale, so that the coating falls off in large sheets with scale adhering.

With a properly prepared surface and good materials, bituminous coat-

ings give excellent satisfaction and have the great advantage that the painting of the inside surface of the standpipe can be done in much less time than with ordinary paint and that there is little danger of any disagreeable taste being imparted to the water.

Lacquers derived from cellulose are now much used, particularly for painting automobiles. They are very costly and are mixed with solvents which in some cases are inflammable and may be injurious to the worker if applied in poorly ventilated places. They are said to be waterproof, and they dry almost instantly.

Application of the Paint.

Assuming that the surface of the steel plates has been thoroughly cleaned and is perfectly dry, it is ready for painting. This should be begun as soon as possible after cleaning, especially if the plates have been sand-blasted, as such surfaces rust very quickly. It is therefore customary to clean only as much surface with the sand blast as can be painted on the same day.

Standpipe Interior. In order to get a hard moisture-resisting film for the inside of the tank, the paint should contain as large a proportion of pigment as will produce a workable paint, that is, one that can be brushed out into a thin film. This is especially important if boiled oil is used; for in this case a thick film would require a very long time to dry and would be liable to be destroyed by the water, even if it seemed dry when the tank was filled. Fine grinding and intimate mixture of the pigment and vehicle by machines, as in the manufacture of pastes and ready-mixed paints, is a great aid to securing a thin, uniform film. The first and succeeding undercoats should not dry with a high gloss, as paint will not adhere well to this kind of surface.

A large proportion of pigment to vehicle tends to reduce gloss, and a little turpentine makes the paint more workable and produces the desired dull surface. The last coat should not contain turpentine, as a glossy surface is desirable, if not obtained at the sacrifice of hardness in the film. A small proportion of finely ground litharge added to all the interior coats seems to increase the hardness and waterproof qualities and hastens the drying of the paint, particularly if red lead is the pigment.

The addition of a very small amount of lampblack paste to red-lead paint produces a light chocolate color suitable for the second coat. A darker shade for the third coat may be obtained by an increased proportion of lampblack.

Standpipe Exterior. The outside paint film does not need to be so hard as that for continuous under-water exposure, although in hot, humid weather there is a film of condensed moisture over the part of the standpipe which is filled with water.

The first coat should be the hardest. The succeeding coats should each be slightly more elastic than the one to which it is applied, in order to avoid

elastic under-coat cracks. The final coat should dry with a gloss, as this increases the durability.

Red lead and raw linseed oil with driers and a little turpentine make a very good priming coat. Owing to the bright color of red lead, it is necessary to follow this coat with two coats, if white or light-colored paint is to be used. A little litharge, about one third of the amount used in the red lead for inside work, expedites the drying and increases the hardness of the red-lead priming coat. It is good practice to have each coat of paint differ in shade or color from the one to which it is applied, in order to facilitate inspection.

On new work, at least three coats of paint should be applied. On a repaint job, the condition of the surface is often the controlling factor. If after thorough cleaning there is a large proportion of firmly adhering old paint, touching up bare places followed by two coats for inside work and one coat for the outside, if the standpipe is enclosed in a building, may be sufficient. If little or none of the old paint survives the cleaning process, three coats should be applied.

Quantity of Paint Required. The determination of the quantity of paint required for a standpipe is rather difficult, as there are numerous factors that affect the result. Some of these are: the kind of pigment and the degree of fineness to which it is ground; the character of the vehicle; the method of mixture with the pigment; and the proportion of the latter to the vehicle. Then there is the condition of the surface as to smoothness and the method of application, whether flowed on in a full coat or well brushed out. A sandblasted surface on new steel plates will take much less paint than a rough, pitted surface, even if well cleaned.

In general, a gallon of paint made with paste red lead and boiled linseed oil will cover about 700 sq. ft. on a sandblasted surface and about the same area with the succeeding coats. If the surface is quite rough, it may take twice as much paint to cover the same area. Outside coats will cover from 600 to 700 sq. ft. per gallon, according to conditions.

A great deal of research work has been done and many experiments have been made by large manufacturers and users of water tanks to find the best paint for this work. The results indicate that red lead best fills the requirements of this severe service.

Regarding the durability of red-lead paint, mixed in the right proportions and carefully applied to a properly prepared surface, a life of from seven to ten years may be expected for paint on the inside of standpipes protected by structures. Probably the life would be somewhat less for unprotected tanks, especially in the northern part of the country. The outside of standpipes in exposed locations may require repainting sooner.

It is evident that the majority of painting jobs on standpipes have a much shorter life, often three years or less, but in such cases it will generally be found that some or all the conditions necessary for good work previously mentioned are not fulfilled. Adequate supervision, good workman-

ship and proper materials are necessary, if the best results are to be obtained.

The durability of bituminous coatings applied hot is subject to the same conditions as to preparation of the surface, suitable materials and proper application, as in the case of paint coats. Under favorable conditions these coatings should last as long or perhaps somewhat longer than the best paint coatings. Thorough preparation of the surface to be coated is even more essential than in ordinary painting. If this is neglected, they may fail even sooner than a poor paint coating.

Specifications for cleaning and painting standpipes and paint formulas, some of which have been in use with good results for many years, together with a bibliography are appended.

Respectfully submitted,

ALFRED O. DOANE, *Chairman.* R. W. ESTY,
C. D. ABBOTT, SCOTT KEITH,
R. D. CHASE, H. J. SKINNER.

APPENDICES.

APPENDIX A.

Specifications for Painting Standpipes.

The contractor shall furnish all labor, machinery, tools, rigging, brushes and all cleaning and painting materials necessary to clean and paint the standpipe in strict conformity with the requirements of the specifications.

Cleaning. After the standpipe is erected and all leaks stopped, it shall be thoroughly cleaned by an acceptable method.

Sandblast Method. The sandblast equipment shall be in good working condition and shall have ample capacity to furnish the required volume of compressed air at sufficient pressure to operate the sandblast effectively. The sand used shall be largely composed of silica grains and shall be sharp and as coarse as it is practicable to use.

The operator of the sandblast nozzle shall be protected from dust by a suitable helmet.

All rust, mill scale, grease, or other material shall be removed from the steel so as to expose the bright metal over the entire surface to be cleaned.

No more area shall be sandblasted than can be painted on the same day that the cleaning is done.

If rust forms on the cleaned surface, from any cause, it shall be removed by the sandblast before any paint is applied.

Motor-driven Wire Brushes. Motor-driven wire brushes shall have ample power and shall be operated at a speed and pressure which will clean the steel thoroughly. Brushes which become badly worn shall be replaced by new ones.

Scrapers and Wire Brushes Operated by Hand. All dirt, rust and loose mill scale shall be removed by means of scrapers and wire brushes.

If any rust forms on the cleaned surface it shall be entirely removed before any paint is applied.

Brushes. Brushes shall be new and of superior quality, having strong and elastic bristles; the brushes shall be of the proper size and shape to admit of thoroughly brushing out the paint without excessive exertion.

Quality of Materials and Provision for Tests. All material to be used in painting the standpipe, for which either standard or tentative specifications have been formulated by the American Society for Testing Materials, shall conform to the latest publication of such specifications.

Litharge shall be pure lead monoxide (PbO) and shall be ground very fine.

Drier shall be of superior quality free from benzine and resin. It shall be made by a manufacturer of established reputation.

All materials, so far as practicable, shall be delivered at the site of the work in original containers showing the brand and manufacturer's name. Sufficient time shall be allowed between the delivery of this material and the beginning of work to collect and analyze samples. No paint shall be applied to the standpipe until approved by the authorized representative of the Owner.

Application of Paint. The standpipe shall be given three coats of paint on both outside and inside surfaces. The first coat of paint shall be applied to the cleaned and perfectly dry surface before rusting begins, the second and third coats shall be applied only under favorable conditions. All paint shall be applied by skilled painters and shall be carefully brushed out to a thin, uniform coating, working carefully around rivet heads, joints and other irregularities in the surface. Each coat shall be allowed to dry thoroughly before the next coat is applied.

The paint shall not be applied during wet or foggy weather, or when the temperature of the air is below 50° F.

Note 1. Stipulations applying to three methods of cleaning standpipes have been included in the specifications. The method best suited to the case in hand should be selected and the corresponding requirements should be incorporated in the specifications. The kind of paint to be used and, unless it is a commercial ready-mixed product, its composition should be stipulated. Paint sprayers may be used for outside painting, but the large proportion of pigment to vehicle in the inside paint makes its application by machines difficult.

Note 2. Repainting Standpipes. If the old paint is in bad condition the tank should be cleaned and painted in accordance with the specifications for new work so far as applicable. If a large proportion of the old paint is in fair condition it may be sufficient to clean the surface with scrapers and wire brushes, touch up bare places and apply two coats of paint instead of three.

APPENDIX B.

Paint Formulas for Standpipes.

Inside First Coat.

Paste red lead	100 lb.
Boiled linseed oil	1⅝ gal.
Fine litharge	10 lb.

Beat up the litharge in one quart of boiled oil and add to paint.

Makes about 4.25 gal. of paint.

Inside Second Coat.

Same as first with addition of ¾ lb. of paste lampblack to each batch.

Inside Third Coat.

Same as first except as follows: Add 1½ lb. of paste lampblack to each batch.

Outside First Coat.

Paste red lead	100 lb.
Raw linseed oil	2⅛ gal.
Drier	1 qt.
Turpentine	1 qt.

Makes about 4.87 gal. of paint.

Outside Second Coat.

Paste white lead	100 lb.
Raw linseed oil	3¼ gal.
Turpentine	1 qt.
Drier	1 pt.
Paste lampblack	2 oz.
Paste French ochre	4 oz.

Makes about 6.00 gal. of paint.

Outside Third Coat.

Paste white lead	100 lb.
Raw linseed oil	3½ gal.
Turpentine	1 pt.
Drier	1 pt.
Paste lampblack	1 oz.
Paste French ochre	2 oz.

Makes about 6.00 gal. of paint.

Note. The above red-lead paint formulas are based on paste red lead, made by grinding 100 lb. of dry red lead with 8 lb. of linseed oil and heavy paste white lead.

If it is necessary to thin the paint on account of cold weather, variation in materials, or to prevent a high gloss, pure turpentine should be added to the under-coat mixtures, but not over ½ pint to a gallon of paint, for the first and second coats, and none at all in the final inside or outside coat. Use a little more oil instead. Paint for inside coats should be as thick as it is practicable to brush out to a thin film.

Stir lampblack or other paste pigments with a small amount of paint until fluid, before adding to the main body of paint.

Paint containing litharge should be used before it begins to thicken from the action of the litharge on the oil.

It is of the utmost importance to allow sufficient time between coats for the paint film to dry thoroughly. The last coat on the inside should be allowed to dry at least one week, under favorable conditions, and longer in cold weather, before filling the tank.

Ready-mixed Paints.

Composition of Paints as Given by a Leading Manufacturer of Lead Products.

Inside of Standpipe.		Per cent. by Weight.
First coat, color orange-red,	Red lead	79.69
weight 28 lb. per gal.	Raw linseed oil	19.31
	Liquid drier	1.00
100 lb. = 3.57 gal. paint.		
Second coat, color light brown,	Red lead	79.05
weight 26.75 lb. per gal.	Lampblack	0.35
	Raw linseed oil	19.75
	Liquid drier	0.85
Third coat, color dark brown,	Red lead	76.23
weight 25.19 lb. per gal.	Lampblack	1.40
	Raw linseed oil	21.34
	Liquid drier	1.03
100 lb. = 3.97 gal. paint.		

Add to the first and second coats 2 lb. of litharge, mixed with ½ pint of pure turpentine for each gallon of paint.

Add to the third coat 2¼ lb. of litharge mixed with ½ pint of raw linseed oil.

All paint to which litharge has been added should be used before the paint begins to thicken.

Outside of Standpipe. For the *outside*, first coat, use same paint as the *inside* first coat, without addition of litharge.

The second and third coats may consist of any good ready-mixed paint of the color specified by the owner.

Use of Dry Red Lead in Making Paint.

Paint made with dry instead of paste red lead is subject to the following disadvantages. The contents of unaltered litharge in the commercial pigment may vary between 2 and 20 per cent., making it difficult to determine the proper amount of litharge, if any, to add for the inner coats. The red lead is generally coarser than that used in paste to start with and is not ground in oil by paint machines in the process of manufacture. For this reason it requires almost constant stirring during application in order to obtain a uniform coating and does not work so well under the brush.

It is more difficult to mix the dry pigment than the paste with oil and there is some danger of injurious effect on the health of the workmen in using the dry pigment.

When for any reason it is necessary to use a paint made with dry red lead and oil, the proportions for under-water exposure should be 100 lb. of dry red lead and 3 gal. of boiled linseed oil, together with about 10 lb. of litharge if the red lead contains 2 per cent. of litharge, or less than 10 lb. if the proportion of litharge in the red lead is larger. The additional litharge should be mixed with sufficient oil to make a thin paste before being added to the paint. If the pigment contains more than 10 per cent. of litharge, no litharge need be added.

The second and third coats should be the same as the first coat with the addition of lampblack, as in the paste red lead formulas.

The outside priming coat should be the same as the inside first coat except that the litharge is omitted.

APPENDIX C.

Hot Coatings.

Hot coatings are ordinarily applied to the inside of the standpipe only. They generally consist of a priming coat applied cold and a second applied hot, both made of bituminous materials.

When hot coatings are employed, it is of vital importance to have the cleaning of the steel done in the most thorough manner, so that the bare metal is exposed over the entire surface to be coated.

The coatings are generally applied by the manufacturers or their representatives, and the work should be done by their own methods if they are to be held responsible for the results.

The outside painting is generally done under the same contract, using ordinary painting materials. The specifications and formulas previously given for outside painting are applicable to this part of the work, or the contractor may be allowed to use paints which he is willing to guarantee in a satisfactory manner.

APPENDIX D.

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PROGRESS REPORT OF THE COMMITTEE ON WATER-MAIN DISINFECTION.

BY E. SHERMAN CHASE.*

The Committee on Water-Main Disinfection as originally appointed consisted of F. B. Forbes, T. E. Lally and E. S. Chase. Later, due to the regrettable death of Mr. Forbes, F. W. Gilcreas was appointed as his successor.

The Committee is not ready to submit a final report but does wish to give an account of progress made to date.

The disinfection of water mains is a live issue, as indicated by the number of published articles dealing with the subject. A brief bibliography is attached to this report

During the past year, the Committee sent out a questionnaire to nearly two hundred superintendent members of this Association requesting information as to existing practice in water-main disinfection. Replies were received from 45 superintendents. These replies may be summarized as follows:

Superintendents using no disinfectant	31
Superintendents using disinfectant	14

Of those disinfecting mains, 2 report using chlorine alone, 7 using hypochlorite of lime alone, 1 using H. T. H. alone, and 4 using both hypochlorite and chlorine. Those using chlorine as well as hypochlorite, employ the chlorine generally for the treatment of larger mains.

The superintendents who do not disinfect new mains invariably take precautions to keep the pipe clean and to give newly laid mains a thorough flushing before placing them in regular service.

Some of the replies relating to the disinfection of mains are of considerable interest. One of them was received from H. Lester Newhall, Engineer of Water Works of Akron, Ohio, and is worthy of being quoted at length. Significant paragraphs from his letter follow:

We discontinued distribution of our pipe on the street much in advance of construction, several years ago as the possibilities of contamination were considered a severe menace to the purity of the water. In some instances even 6-in. pipes have been contaminated by flooding of trenches by broken or overflowing sewers, and in such cases the lines are invariably chlorinated and flushed till analyzed and pronounced satisfactory by our Chief Chemist.

During construction, we insist upon insertion of a galvanized-iron plug in the end of the pipe to keep out rats, cats, etc., as well as mud and stones, and the end of the pipe is always covered with a couple of feet of earth before leaving the job at night. This keeps boys from throwing stones, old shoes, tin cans, bones, etc., into the line when the men are off the job.

Your committee may be interested in a rather unpleasant experience which we had in a ¾-mile line of 36-in. cast-iron pipe laid by a contractor in 1927. Owing to topographic conditions this line had two pockets which could not be drained except by pumping, one under the Little Cuyahoga River which is very seriously contaminated by sewage and factory waste and the other in a rock cut to pass under a double track railroad.

During construction at the river crossing the contractor was repeatedly warned against allowing the river water to rise in the cofferdam to such height as to enter the pipe, but this happened and although an attempt was made to wash out the 100 feet of pipe affected at the time, the analysis, after the pressure test, of the complete line indicated absolute contamination.

The line was drained and the interior surface of the pipe, from the entrance manhole at the river to the railroad sump was washed down with "gold dust" and water, as there seemed to be a greasy film over the entire surface. Upon completion of this washing, there was a greasy smoothness but the pipe was considered clean and again filled.

Analysis after two days indicated that the water was entirely unfit to pass into the distribution system, and as the contractor protested washing down the entire line, it was filled and emptied through the blow-off at the lower end five times at about 48-hour intervals. As analysis still indicated contamination and the contractor refused to wash

*Chairman of the Committee.

it out, we gave the line a complete hand washing with chloride of lime and water at his expense. This required about ten days, and upon completion the entire line was carefully inspected, filled with water and drained after 48 hours. Forty-eight hours after it was again filled analysis indicated that it was still unfit for use, and we put in 80 lb. of liquid chlorine, feeding it in through the upper end as the pipe was filled. Forty-eight hours later, the line which was put in as an emergency to meet heavy summer drouth was flushed, filled and pronounced O. K.

In laying another 36-in. main in 1928 our inspector found the bulkhead in the end of the pipe dug out on several occasions, and upon investigation we found that small boys had been going into it nights and had committed considerable nuisance. As the contractor in this case had carefully washed each pipe before it went into the ditch, he was considerably disturbed over the incident and the boys' families were dealt with. The particular locations were cleaned, and in this case the mile of pipe passed the analysis and pressure test upon the second filling.

The practice of W. W. Brush of New York City is illustrative of the methods employed in the disinfection of mains. In New York, both chloride of lime and liquid chlorine are used, the latter being used to sterilize mains larger than 20 in. in diameter. Sufficient disinfectant is applied so that the water in the section of the main being disinfected contains approximately 5 p.p.m. of free chlorine. Chloride of lime is applied by placing it in the bottom of the pipe when laid, and the water as it is fed into the pipe absorbs the free chlorine. Another method of applying the chloride of lime is to pump it as a solution into the main, through a corporation cock at one end of the line while the line is being blown off at the other end. In the case of liquid chlorine this disinfectant is usually applied by the use of chlorine-control equipment, manufactured by the Wallace & Tiernan Company.

It is planned to allow the disinfectant to remain in contact with the mains for two hours in the case of the smaller mains or for four hours or longer in the larger mains.

In connection with the use of chloride of lime, it is planned to accomplish definite change of water in the main after no chlorine can be detected in the water being discharged. In the case of liquid chlorine the water from the discharge is tested until no residual chlorine is obtained.

Samples from mains 12 in. and larger in diameter are analyzed by the laboratory and must prove sterile before being placed in service. It has been found very helpful in obtaining sterile conditions to flush the main which is to be used as a feed before filling or flushing the new main. If the old main is flushed at a higher rate than will be used in flushing the new main, any sediment in the old main will be removed, thereby preventing such material from being carried into the main to be sterilized. Experience has indicated that where this precaution is carefully observed, sterile conditions will usually result in the new main without the use of disinfectant, but notwithstanding this condition, a disinfectant is always applied as an additional precaution.

While the committee is not as yet ready to make definite recommendations relative to the disinfection of water mains, it wishes to point out the fact that many superintendents consider water-main disinfection a desirable sanitary precaution.

It is true that in many water works no disinfection of water mains has ever been carried out and, so far as information is available, without serious water-main contamination. It must be remembered, however, that no one can foresee when disastrous contamination may result through unfortunate combinations of circumstances. For this reason it seems as though the precaution of disinfecting newly-laid water mains were well worth while, and we wish to leave this thought with our fellow members of the Association.

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PROGRESS REPORT OF COMMITTEE ON STANDARD SPECIFICATIONS.

BY C. W. MOWRY.*

The committee for which I am reporting is a new one in this Association, appointed by Arthur D. Weston when he was president last year. Our work is to review the reports made by the standing committees of the Association and make whatever recommendations to the Executive Committee that we feel should call for action by the Association as a whole.

Committee of American Standard Association and Standardization of Small Hose Threads. (J. L. Howard, Chairman of Committee.) After a good deal of consideration the American Standards Association felt that it was impossible to have one fixed standard for small hose threads, because where there are quick and frequent connections a coarse and heavy thread is preferred. Hence, they have proposed to set up the following standards: For garden hose, sizes ½-, ⅝- and ¾-in., they propose 11½ threads per in.; for chemical fire hose, ¾- and 1-in., they recommend 8 threads per in.; for general fire protection, small hose, 1½-in. size, 9 threads per in. For air, water, steam and general purposes they are using the wrought-iron pipe thread,— that is, 14 threads per in. for ½- and ¾-in. hose, and 11½ threads per in., for 1¼-, 1½-, and 2-in. hose. This standard has been given the approval of the Sectional Committee of the A. S. A.

Sponsors of the Sectional Committee of the American Standards Association on Standardization of Cast-iron Pipe and Special Castings. (W. R. Conard, Sponsor Representative.) The Sectional Committee met in New York City, March 26, 1930 with C. W. Mowry and W. R. Conard present representing the NEW ENGLAND WATER WORKS ASSOCIATION. The Chairman of the various Technical Committees, of which there are three, reported as follows:

Technical Committee No. 1 on Dimensions and Weights, Pipe and Fittings reported progress in that its various Sub-Committees were active with one exception, but from which it was expected some definite work would be had during the ensuing year.

Special Sub-Committees have been appointed to study the voluminous reports of tests made, being made, and to be made.

It is generally understood that at the next Sectional Committee meeting, Technical Committee No. 1 will probably be able to report very substantial progress on the work assigned it.

Technical Committee No. 2 on Metallurgy, Processes, Tests reported further progress on tests assigned to it but was unable to give a final report as final tests were not yet complete.

Technical Committee No. 3 on Corrosion and Protective Coatings, as in the past, has been able to make more progress with its work on account of there being data available on corrosion and coatings in the way of tests already made and coatings or linings used of known characteristics. There is hope that this Committee's work will be sufficiently advanced by the next Sectional Committee meeting so that it will be possible to present tentative specifications for the part under their charge.

The Executive Assistant, A. V. Ruggles, is working hard to keep matters caught up to date so that the Sectional Committee can report Specifications to the American Standards Association for adoption with little or no delay after they are ready for submission.

Sectional Committee of the American Standards Association on Specifications for Cast-iron Pipe and Special Castings. (C. W. Mowry, Representative.) The work of Technical Committee No. 1, dealing with the design and dimensions of pipe and fittings is at a standstill because of lack of sufficient experimental data. As nearly half of the pipe now being made is manufactured by the centrifugal and horizontal processes, standard specifiations for these types of pipe are most important, but before the specifications and pressure ratings can be completed, more laboratory tests are needed on 6-in., 12-in. and 20-in. sizes. It is expected that these tests will be made during the coming year.

*Chairman of the Committee.

Technical Committee No. 2, dealing with metallurgy processes, reported that a study of breaks in underground cast-iron pipe has indicated that failures after installation are due mainly to unequal settlement of the ground, local bearing on stones or other hard objects, excessive loads and vibration, water hammer, and temperature changes. Most breaks were near the middle of the pipe due to beam action, and only a few were due to poor metal. The Committee concluded that what is needed is not an increase in the strength of pipe or changes in composition of the metal, but proper selection of class of pipe required for the particular service and for meeting any special or unusual conditions, careful inspection in foundry and field, and greater precautions in handling and installing the pipe.

Professor Schlick of Iowa State College is conducting tests to represent trench loading under various combinations of external load and internal water pressure. He found that a 20-in. pipe required a load of 18 000 lb. per lineal foot to crack the pipe; and under internal pressure alone, it required 1 500 lb. to burst the pipe. The tests are being continued with intermediate values of external load and internal water pressure.

Professor Enger of the University of Illinois has been making bursting tests of cast-iron elbows, tees and crosses. These fittings failed all the way from 320 lb. up to 1 200 lb. per sq. in., the weakness apparently being due to the unsupported flat surfaces of these fittings. Although these bursting pressures are much less than those of pipe of the same size, it is significant that very few fittings actually break in practice. The bursting tests are to be continued with short pieces of straight pipe attached to the fittings, to more nearly represent actual field conditions.

Technical Committee No. 3, which is working on the problem of pipe corrosion and protective coatings, reported that a 2-year study at the Massachusetts Institute of Technology has been completed. The matters investigated included the effect of iron composition and method of casting, upon the rate of corrosion. There were greater variations of corrosion on samples of identical products than among different materials. The causes of these variations have not yet been found, and the work is to be continued.

The study of organic pipe coatings is just being started at the new dipping plant of the American Cast Iron Pipe Company, at Birmingham, Ala. The tests will include variations in dipping conditions as well as in the coating material itself. Experimental coatings will then be subjected to a variety of field tests, with the idea of standardizing the process of foundry dipping. Exposure tests of inorganic coating, such as cement lining, are under way, to determine the effect of varying thicknesses of lining, kind of cement, and percentage of sand.

It will probably take two years more to complete the strength tests of pipe and fittings, the friction loss tests on fittings, and other work under way necessary to complete the preparation of standard specifications, giving dimensions of all kinds of cast-iron pipe and fittings.

Committee of American Standards Association on Simplication of Manhole Frames and Covers. (W. R. Conard, Representative.) There has been no activity of this Committee for some time, no meeting having been called since my appointment. However, Simplified and Standard Manhole Frames and Covers is a live subject and it is probable that something will be done along these lines before long.

Committee of American Standards Association on Pipe Flanges and Fittings. (W. R. Conard and F. A. Barbour, Representatives.) Since September, 1929, there has been one meeting of this Committee. There has been a ballot on the 25-lb. Cast-iron Flange Standard, which had been recommended by the Sub-Committee having it in charge, but I do not seem to have any information of the result of the vote on this Standard. Progress has been made on Standards for the 125-lb. Cast-iron Standard, and also for Steel Flanges for higher pressures and for super-heated steam up to 750° F.

A communication has been received from the Chairman of the Sectional Committee on Standards of Pipe Flanges and Fittings giving the result of the ballot on 300-lb. cast-iron flanges and flange fittings. This ballot was voted upon favorably for recommenda-

tion as a tentative standard. The Manufacturers Standards Society, however, has entered a reservation. The ballot that was adopted called for the fittings to be clearly marked indicating the maximum working pressure, and with the letters "C. I." for cast iron, "S" for steel, and "W. O. G." designating the fitting as intended for use in water-, oil- or gas-pipe systems. The Manufacturers Standards Society objected to the rather voluminous marking called for. On the other hand the Committee, in discussing the standards, felt that it was quite necessary that all these markings be placed on pipe and fittings.

Sectional Committee of American Standards Association on Code for Pressure Piping. (F. N. Speller, Representative.) There has been little change made in the code for power piping as last published except for a few editorial corrections. At the December, 1929, meeting, it was unanimously moved to allow wrought-iron bolts for pressures up to and including 125 lb.

Sub-Committee 4 on Gas and Air Piping stated that the Code was in final form except for any changes or redrafting that might be necessary as a result of requests from the natural gas industry. They expect to have this work completed in time for the December, 1930, meeting.

Sub-Committee 5 on Refrigeration Piping reported that it is impossible to get any one in the refrigeration field to take any interest in the preparation of a Piping Code for this class of piping.

Some slight modifications in the Oil Piping Code were made including a section for higher pressure and temperature rating of 1 500 lb. and 900° F.; also an amplification of cast-iron pipe requirements (at the request of the cast-iron pipe interests).

In regard to Piping Materials and Identification (Sub-Committee 7) the question of an appropriate identification mark is being considered. Nothing definite has been decided.

The Committee is also considering a section on hangers, supports and anchors. Very little has been done on this up to this time.

NOVEMBER MEETING.

ENGINEERS' CLUB, BOSTON, MASS.

Wednesday, November 12, 1930.

President George H. Finneran in the Chair.

The Secretary announced the election of the Executive Committee of the following members: Edward Bartlett Riley, Assistant Engineer with F. A. Barbour, Malden, Mass.; Edward J. O'Brien, Superintendent, Water and Sewer Departments, Arlington, Mass.; Kirk Bryan, Associate Professor of Geology, Harvard University, Cambridge, Mass.

Robert E. Horton and Benjamin Smith gave illustrated talks on "The New Albany Water Works." Mr. Diven of The Leadite Company exhibited a moving picture showing the handling and laying of the 48-in. pipe and the trenching operations on this work.

(*Adjourned.*)

DECEMBER MEETING.

HOTEL BRUNSWICK, BOSTON, MASS.

Wednesday, December 10, 1930.

President George H. Finneran in the Chair.

THE PRESIDENT. I wish to announce that at a meeting of the Executive Committee this morning it was voted to hold our next annual convention in Boston. A committee will be appointed shortly to prepare the way for the September event.

One of our members asked me to urge the city and town representatives who are with us to do what they can to speed up their program of construction and maintenance for the coming year. The idea, of course, is to start whatever work is planned as early as possible to help out the unemployment situation. We all know about it and probably are doing whatever we can to assist.

ROGER W. ESTY. Mr. President and members of the NEW ENGLAND WATER WORKS ASSOCIATION: Before I read my paper, I have a few remarks I want to make regarding the past, present and future of the NEW ENGLAND WATER WORKS ASSOCIATION. It seems to me that lately the meetings of the Association have been lacking in interest. I believe that we should get more of the superintendents to enter into the discussions, write papers and present them before this Association. This would create more interest and make everyone want to come and not miss one of our meetings. We want these meetings to be the biggest event each month in our business.

A paper, "Experiences with Water Mains and Cement-lined Pipe at

Danvers, Mass.", was read by Roger W. Esty, Superintendent, Danvers Water Works, Danvers, Mass. This paper was discussed by Morrison Merrill, David A. Heffernan, Henry A. Symonds, William Naylor, Henry T. Gidley, Stephen H. Taylor, W. Guy Classon, George C. Brehm, Joseph A. Hoy, Arthur C. King, Mr. Wise, Frank T. Gifford, Richard H. Ellis, Caleb M. Saville and Herbert C. Crowell.

A paper, "The 1929–1930 Drought in New England and Resulting Water Works Problems", was read by H. B. Kinnison, District Engineer, Water Resources Branch, U. S. Geological Survey, Boston, Mass., and discussed by Stephen H. Taylor, Arthur D. Weston and Arthur C. King.

(*Adjourned.*)